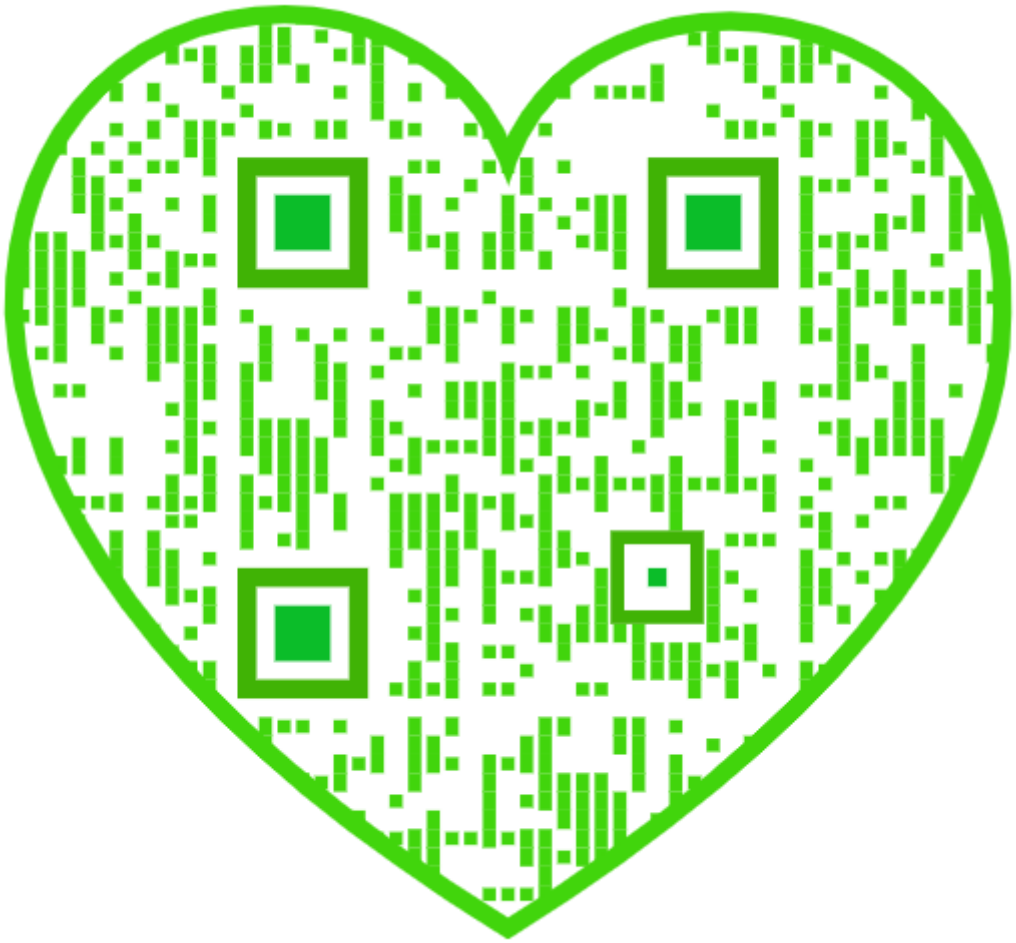

SHOPS AND SHOP PRACTICE

VOLUME II.

THIS BOOK (In Two Volumes) EXPLAINS AND ILLUSTRATES BY DRAWINGS, ETC., THE LOCATION AND ARRANGEMENT OF SHOPS AND STOREHOUSES; THE CARE AND REPAIRS OF LOCOMOTIVES AND CARS; THE PRACTICAL WORK ACCOMPLISHED IN THE SHOPS, SUCH AS LATHE WORK; PLANER AND SHAPER WORK; SLOTTING MACHINE WORK; MILLING MACHINE WORK; GEAR CUTTING; INTERNAL COMBUSTION ENGINES; ERECTING ENGINE TRUCKS, FITTING UP CYLINDERS, VALVE GEAR RODS AND DRIVING BOXES; HANGING GUIDES; LAYING OUT SHOES AND WEDGES; SPRING RIGGING; PIPE FITTING; SETTING VALVES; INJECTORS; BRAKE VALVE; AIR PUMP AND TRIPLE VALVE REPAIRS; LAYING OUT BOILER WORK, ETC.

FORMING ONE OF THE SERIES OF VOLUMES COMPRISED IN THE REVISED AND ENLARGED EDITION OF

THE SCIENCE OF RAILWAYS

BY

MARSHALL M. KIRKMAN

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CHAPTER XVII

ERECTING SHOP WORK—CLEANING AND REPAIRING TRIPLE VALVES.

Triple valves are made in a variety of styles and sizes, depending on the service for which they are designed, and are designated by a "plate number" which is cast on the triple body. The Westinghouse triple valves in general use are as follows, and should not be used other than as specified:

Equipments.	Class of Service.	Diameter of Cylinders Inches.	Approximate Light Weights for Cylinder Sizes Specified. Pounds.	Style of Triple Valve	Auxiliary Reservoir. Inches.
Driver Brake	All Locomotives, with or without Truck Brake or High-Speed Attachments.	8	..... to 40,000	H24	10x33
		10	40,000 to 85,000	H24	12x33
		12	70,000 to 115,000	F46	14x33
		14	110,000 to 170,000	F46	16x33
		16	145,000 to 225,000	F46	16x42
Tender	Passenger-Engine Tenders.	8	15,000 to 30,000	F36	10x24
		10	30,000 to 47,000	F27	12x33
		12	47,000 to 68,000	F29	14x33
	Freight and Switch-Engine Tenders.	8	15,000 to 30,000	G24	10x24
		10	30,000 to 47,000	G24	12x33
		12	47,000 to 68,000	F25	14x33
Car	Passenger Cars.	8	15,000 to 30,000	F27	10x24
		10	30,000 to 47,000	F27	12x33
		12	47,000 to 68,000	F29	14x33
		14	68,000 to 92,000	F29	16x33
		16	92,000 to	F29	16x42
	Freight Cars.	6	... to 15,000	F36	Standard Cast-Iron Reservoir.
		8	15,000 to 40,000	F36	
		10	40,000 to	H49	

For a full description of the construction and operation of these various forms of triple valves the reader is referred to the volume of The

Science of Railways devoted to the air brake. In this same volume will be found a full description of the diseases with which triple valves are affected and the cures for the same. Before attempting to do work of any description on triple valves, the machinist should thoroughly inform himself on the subject matter referred to above.

In the following pages the methods to be pursued in cleaning and repairing triple valves will be taken up. These valves should be cleaned at least once in six months and, when possible, should be removed and sent to the repair room for this work, placing a repaired and cleaned valve in place. *A defective triple valve should always be replaced by one in perfect condition*, the defective one to have a tag affixed stating for what reason it was removed, before being sent to the repair room.

In roundhouse work, for various reasons, it is not always possible to comply with the above instructions, hence we will first take up the cleaning of a driver brake triple valve in position.

The triple valve should be cut out and the auxiliary reservoir bled. Referring to Fig. 1, the graduating stem nut 10 should be loosened before the cylinder cap 3 is removed. If this is done it will probably save a trip to a vise or the replacing of the cap. Remove the cylinder cap and withdraw the piston 5 and slide valve 6, placing them in a can of kerosene to loosen up the dirt and gum. Then wipe out the

cylinder and slide valve bushing with a piece of cloth. *Do not use waste,* as small pieces are liable to get into the ports and cause trouble. Clean out the feed groove with a hard-wood stick. Next examine the condition of the graduating stem 8, graduating spring 9, and

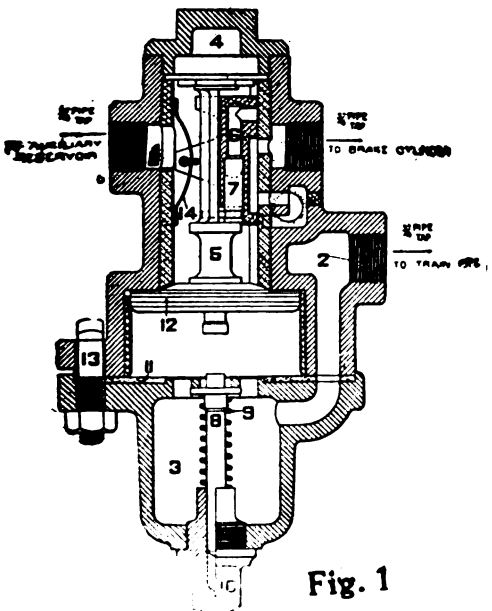


Fig. 1

graduating stem nut 10. The nut should be thoroughly cleaned out, as from its position the dirt and rust tend to accumulate in it, and this accumulation will cause the graduating stem to stick. Examine the graduating spring and if it is not of standard length as specified

by the air-brake company it should be renewed. The standard springs for the F25, F46, G24 and H24 plain triple valves consist of 12 coils, 2½ inches free height. The graduating stem should be cleaned and should be tested to see that it works free in the graduating stem nut. Examine the cylinder cap gasket, and if in good condition it should be cleaned by rubbing briskly with a piece of cloth. *Do not scrape it with a sharp tool.*

The piston should be removed from the kerosene and the packing ring worked around in the piston until all dirt is worked out of the groove. In doing this be careful not to spring the ring. Wipe off all kerosene and oil the ring with a few drops of engine oil, also the slide valve, and place the piston in the cylinder and work it back and forth a few times, after which remove it and thoroughly clean again. Place a few drops of oil on the piston, slide valve and cylinder, place in position and bolt up the cylinder cap. Then place the graduating stem and spring in place and tighten the graduating nut.

The triple should now be cut in and the brake applied several times in service and emergency, and all joints, as well as the exhaust port, tested for leaks.

The same methods should be pursued if it is necessary to clean a tender triple valve in position, and no work other than above described should be attempted on valves in position.

Repair Room Cleaning, Repairing and Testing.

As was before stated all triple valves removed should have a tag affixed stating the defect for which the valve was removed. As these tags will sometimes become detached, and also as a check on the men making the removals, all triples coming to the repair room should be placed on the testing rack and any defects noted. In general, this test should be made in about the following manner:

When air is turned on for charging, if there is no leak from the exhaust port, the time required to charge the auxiliary reservoir should be noted. With a constant train-pipe pressure of 90 pounds, the auxiliary reservoir should charge to 70 pounds in 55 seconds, and it should not take less than 45 seconds nor more than 60 seconds. If it takes less than 45 seconds it indicates that either the feed groove has been enlarged, or there is a defective piston packing ring and a poor fit of the piston against the end of the slide valve bushing. If it charges too slow it indicates that the feed ports are clogged up.

When a slight leakage at the exhaust port commences with the charging and increases as the auxiliary reservoir accumulates pressure, a leak from the auxiliary reservoir would be indicated, and this would, of course, affect the time required for charging. If a very gradual but steady reduction in the train pipe pressure be made, a leak from the auxiliary reservoir will retard or prevent the application of the brake,

but if the leak is from the train pipe side of the triple valve it will hasten the application of the brake. If the triple makes a good joint where it is fastened to the rack, it is evident that the slide valve is causing the leak from the auxiliary reservoir. If the leakage is from the train pipe it may be either passing by the emergency valve or the joint between the large and small openings in the check valve case gasket.

When a triple valve is reported as leaking at the exhaust port, but shows no leak when tested on the rack, it is evident that the trouble was not with the valve, but might have been caused by a leaky gasket between the triple valve and the brake cylinder head if a passenger triple, or if a freight triple valve the leak might have been in the gasket between the valve and the auxiliary reservoir, or a leak in the tube running through the auxiliary reservoir from the valve to the brake cylinder.

With the brake fully charged, make a five-pound reduction, place the valve handle on lap and observe if the brake cylinder pressure continues to increase, or if the triple valve releases. Should the triple valve release, or continue to increase the brake cylinder pressure, it indicates that probably the graduating valve is leaking. However, should a blow commence at the exhaust port following the light reduction, it is probably caused by a leaky slide valve and may cause the valve to release. If it fails to release, the train pipe being abso-

lutely tight, such failure to release would probably be caused by the small volume of the train pipe together with leakage past the triple piston packing ring.

The next test should be made by emptying the train pipe and leaving it open. Should the triple valve develop a leak at the exhaust port, it is probably due to the slide valve being raised up at the back end on the shoulder left on the seat by the short travel in the ordinary service applications. Suppose no leak shows at the exhaust port, and it is known that the brake cylinder is tight, observe if there is any decrease in the brake cylinder pressure, and whether there is a discharge of air from the open train pipe. If there is, there is back leakage either by the check valve or triple piston, or both. The leakage past the piston should be prevented by the packing ring and also by the joint the piston makes on the cylinder cap gasket.

Whenever after an emergency application and release, or even following a release preceded by an excessive service reduction, an exceptionally heavy blow commences at the exhaust port, but the brake does not release, this is generally due to the emergency and check valves sticking together, or the emergency piston being held in its lowest position by reason of a bent emergency valve stem.

A bent triple piston stem will hold the slide valve off its seat, thus causing a leak at the exhaust port. It is generally caused by loosening

the nuts on the cylinder cap while there is pressure in the auxiliary reservoir, or by a cylinder cap gasket of uneven thickness.

With the plain triple valve, a leaky slide valve or graduating valve will have the same effects as above described, and will be located in the same manner. The old E22 valves, having a four way cock in the body, are fast becoming obsolete, and a majority of the ones remaining in service have this cock so fixed that it cannot be operated, so that they are practically identical with the improved forms of plain triple valves. However, with valves having this four way cock, a leak past it would have the same effect as a leaky emergency valve. The best way to test this cock is to cut out the brake and bleed the auxiliary reservoir. Take down the cylinder cap and put on a leather gasket that will close the supply port, and put the cap back with the port closed. Then cut the brake in. If the cock leaks the valve will blow at the exhaust port. In making this test the triple piston should be in release position and the brake cylinder connection should be plugged. With the plain triple a well fitting piston packing ring is as essential as with the quick action type.

MAKING REPAIRS.

The triple valve, Fig. 2, should be taken apart and all parts, except the gaskets and rubber seated valve, should be placed in a bath of kerosene, taking care not to mix the parts

of different valves. The kerosene will soften the dirt and gum which will make the parts quite easy to clean. The valve body should be secured to the bench in a manner most convenient for the workman. Fig. 3 shows a tool

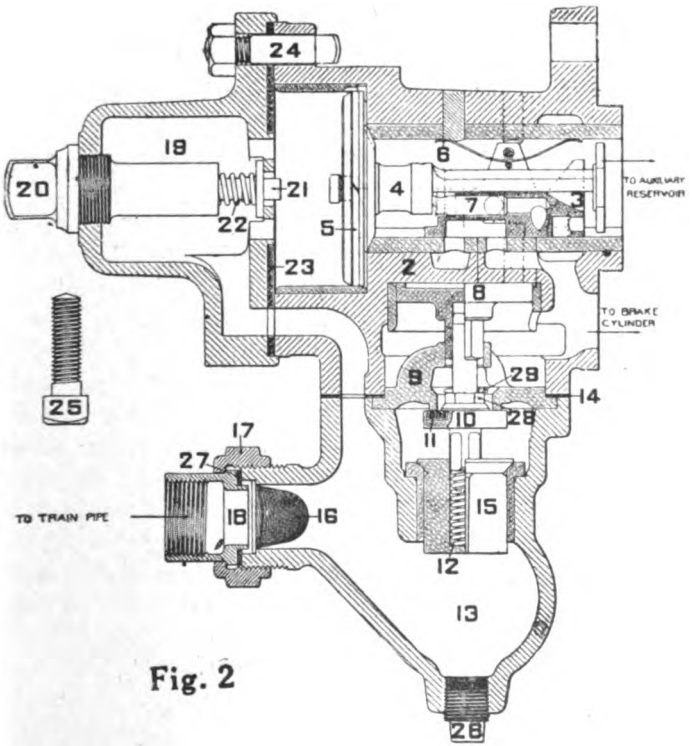


Fig. 2

for holding the triple valve in a vise, by means of which the valve can be rotated, and also raised and lowered to the most convenient position.

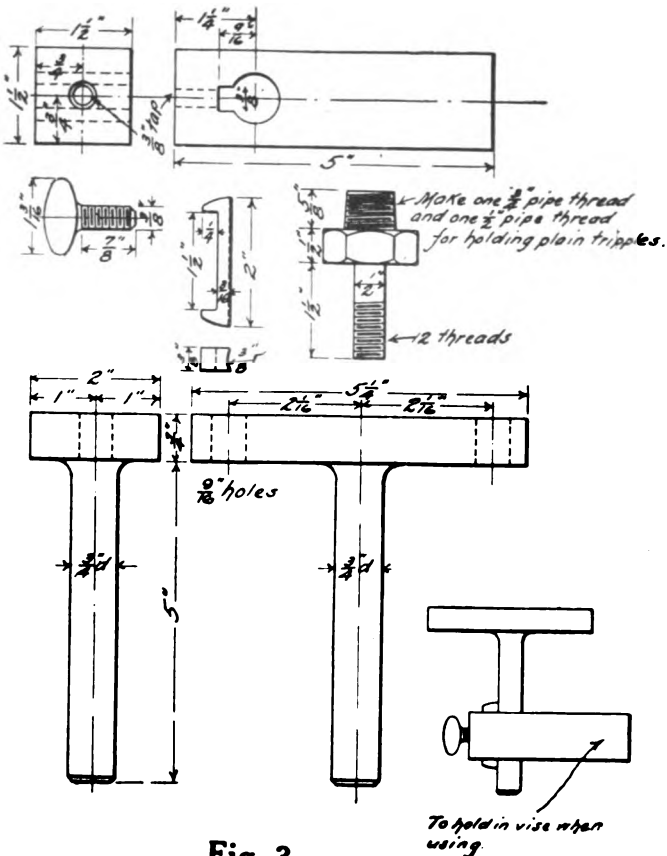

Make one 3/8" pipe thread and one 1/2" pipe thread for holding plain tripples.
12 threads
holes
To hold in vise when using.

Fig. 3

Slide Valve. In the absence of special tools for facing the slide valve seat, it may best be brought to a true surface by filing down the high spots, using a file having straight faces, and also safe edges, so as not to cut into the sides of the bushing. After filing, the seat should be brought to a perfect plane by using a long, narrow, face plate, as shown in Fig. 4, and scraper. The slide valve should then be scraped to a perfect bearing with an accurate face plate. Then the valve and seat should be

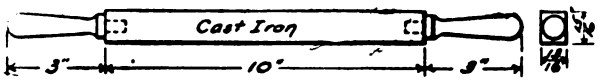


Fig. 4

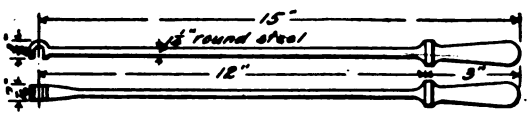


Fig. 5.

ground together, stopping the instant a good bearing is secured. This grinding should preferably be done with oil only, but if grinding material is used, it should be of the finest grade of Trojan compound or powdered pumice stone. Fig. 5 shows a tool for moving the slide valve back and forth while grinding, the hook on the end taking the place of the slide valve spring on the pin across the valve so as to evenly distribute the pressure on the valve. The edges of the valve seat at *a* and *b*, Fig. 6, should be

scraped lower than the balance of the seat. Some workmen report good success in facing the slide valve by grinding it down on a flat block of lead charged with grinding material. Emery should never be used on any of the parts of a triple valve, as it beds itself in the brass and cannot be entirely gotten rid of. If the exhaust cavity in the slide valve becomes too shallow, the valve should be thrown away and a new one fitted. The round-faced valve and seat may be brought to a bearing together by using a round-nosed scraper and a little grinding.

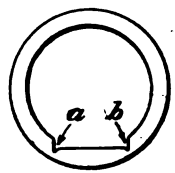


Fig. 6

Graduating Valve. The seat for the graduating valve in the slide valve should never be reamed unless absolutely necessary. The valve should be ground to a perfect joint and should be tested for straightness, and also for length. If the hole in the head for the graduating pin should be badly worn, the valve should be discarded, but it should be remembered that a small amount of lost motion at this point is necessary. The graduating pin should be examined to see that it is not loose, and if necessary to put in a new pin it should be soldered in place and should stand at right angles to the

flat part of the piston stem. In case the seat has been reamed so that a new graduating valve is too short, the slide valve should be scrapped.

Piston Packing Rings. Rags saturated with kerosene should be used to clean the triple cylinder. The feed grooves should be thoroughly cleaned, care being used to see that they are not enlarged. The triple piston should be placed on centers in a lathe to determine whether the stem is bent or not, and if found bent it should be carefully straightened. A convenient tool for testing the truth of triple pistons is shown in Fig. 7, and needs no further description. The distance from the face of the piston to the end of the knob on the rod should be gauged to determine if it is standard. *The packing ring should never be removed unless it is to be destroyed.* This ring should be a neat fit in the groove and the ends where cut should not be more than 1-64 inch apart when the piston is in the cylinder. The cylinder bushing should be true and without more than a barely perceptible shoulder in it. If a triple valve needs a new bushing, it should be sent to the manufacturers for repairs. In fitting new packing rings the repair man should bear in mind that *nothing short of perfection* will answer, as a poorly fitting packing ring will result in "stuck brakes," with all the attendant evils of such. The joint the ring makes with the cylinder should be such that no air can pass the piston except when it is in the

release position, and then only through the feed groove. As the rings are turned larger than the cylinder they are to go into, it will be found that when filed open the requisite amount to let them enter the cylinder and have the ends meet, there will be no bearing for some distance back from each point, the ring not being a true circle when closed. Now, if the points should be eased off until a full bearing is had, the ends will not come together. To over-

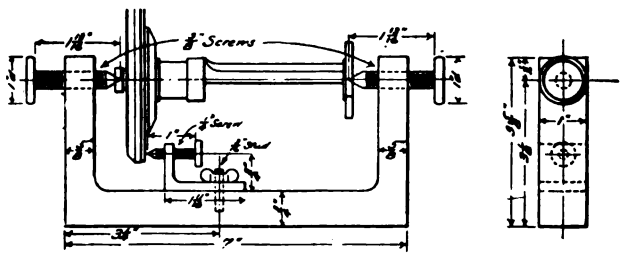


Fig. 7

come this, before entering the ring into the groove it should be filed open until when placed in the cylinder the ends overlap the amount the ring will open during the process of fitting it to the cylinder. The high spots should be reduced by scraping carefully, rubbing the ring back and forth in the cylinder frequently to show where the bearing is too heavy. It should be understood that the bearing of the ring opposite the cut is not to be touched, the high spots near the ends of the ring only to be reduced. This fitting should be continued until

the ring shows a bearing around the entire circumference. The ends of the ring should now be filed until they just touch when the ring is in the cylinder. Now place the ring carefully in the groove, entering it from the thin side of the piston. If it is found that more must be filed from the ends of the ring in order that the piston may enter the cylinder, do so by raising one of the points so that a piece of tin may be slipped between it and the piston, leaving the other end depressed. However, it should be necessary to use some force in entering the piston into the cylinder, as this will spring the ring to a better fit and it can thus be more quickly brought to a perfect bearing by grinding. The piston should be well oiled and worked back and forth until a perfect bearing between the ring and cylinder is obtained. Various forms of grinding machines are in use, one of which is shown in Fig. 8. Some form of a grinding machine is absolutely necessary if any quantity of this work is to be turned out. After the ring is brought to a perfect bearing, the piston should be placed under a press and the groove closed on the ring until you can just move the ring freely with the thumb nail. Fig. 9 shows a tool for holding the packing ring while filing the ends open. The diameter at *A* should be 1-16 inch larger than the bore of the packing ring, so that when the ring is sprung on, the ends will stand open enough to allow filing. The height *B* of the step should be enough less than the

thickness of the ring, so that it will be held firmly when clamped in the vise. The groove across the pieces should be on an angle of 45°, about ½ inch deep and ⅜ inch wide. A dowel pin should be so placed that the two pieces will be held in line. This tool should be made of steel and hardened. The tool shown in Fig. 10 is to fasten on the knob of the piston rod

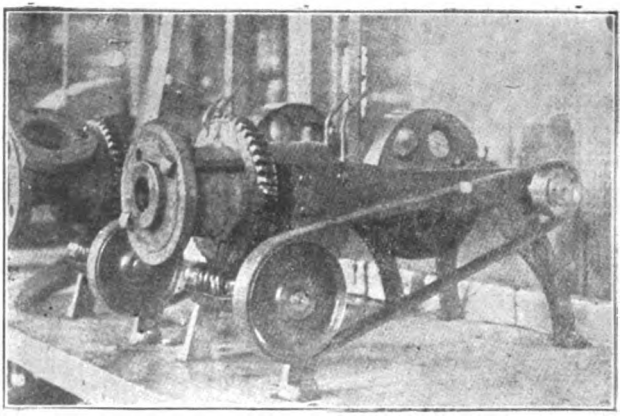


Fig. 8

to move the piston back and forth in the cylinder when fitting the packing ring.

A number of railways make it a practice to send all triple valves requiring new packing rings to the manufacturers for repairs, claiming that this work can thus be done much better and cheaper.

Graduating Stem and Nut. The graduating stem should be gauged to see that the end of

the stem projects beyond the face of the cylinder cap the standard distance, and that the stem is not bent. The graduating stem nut should be thoroughly cleaned out, using a special reamer for this purpose, as the rust and dirt accumulate in this nut and such accumulation will cause the graduating stem to stick. The graduating springs should be examined and any not of standard length as prescribed by

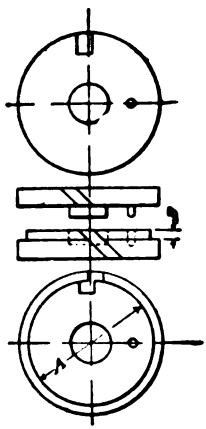


Fig. 9

the brake companies should be discarded, a new one being applied. These springs for the various Westinghouse triple valves are as follows:

Plain triple valves F25, F46, G24 and H24, 12 coils, 2½ inches free height.

Passenger triples F27 and F29, 13¼ coils, 2⅝ inches free height.

Freight triples F36 and H49, 16 coils, $2\frac{3}{4}$ inches free height.

Care should be taken that these springs are not used other than as specified.

The graduating stem should be cleaned, and it should be seen that the stem works free in the graduating stem nut, as this is very important.

The condition of the cylinder cap gasket should be noted, as by the use of a poor grade of oil these gaskets are quite frequently rotted out. As the thickness of this gasket is

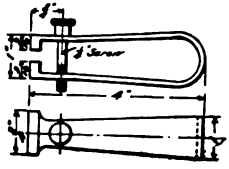


Fig. 10

important, "home-made" gaskets should never be used. The gasket should be cleaned by rubbing briskly with a piece of cloth; do not scrape it with a sharp tool. The triple body is now ready for the cylinder cap, but before assembling the body and cap should be thoroughly blown out.

Emergency Piston.—Usually sufficient attention is not paid to the condition of the emergency parts of the triple, as is shown by their condition. The emergency valve piston bushing should be examined as to its tightness in the body, as these come loose not infrequently.

The piston should be free in the cylinder, and the stem of the piston should fit the hole in the emergency valve seat so that it will act as a guide and not allow the piston to cock. The hole in the piston for the emergency valve stem should be gauged to see that it is the correct size and depth.

Emergency Valve.—The condition of the emergency valve seat should be examined, and if the seat is in any way distorted it should be renewed. In taking valves apart the emergency valve seat sometimes sticks firmly to the check valve case when the latter is removed. When this happens, it may generally be removed by holding the case in one hand and by striking sharp blows around the bearing face just outside the emergency valve seat; the jar, together with the pressure of the check valve spring, will cause the seat to loosen. A wood mallet or soft hammer should be used. Any roughness on either piece which may have caused this sticking should be removed. In case the emergency valve seat remains in the triple valve body and is difficult to remove, use a tool, as shown in Fig. 11. The rubber seats for the emergency valves generally require renewing whenever the valve is overhauled, and for this use only pure rubber seats of standard thickness. The emergency valve stem should be tested with a tool similar to that shown in Fig. 12, to see that the stem is true with the body of the valve. It should also be tested to see that the stem is the correct length, and that

it works free in the emergency valve piston and in the check valve. The check valve spring should be examined to see that it is standard length and a new one used, if necessary. Do

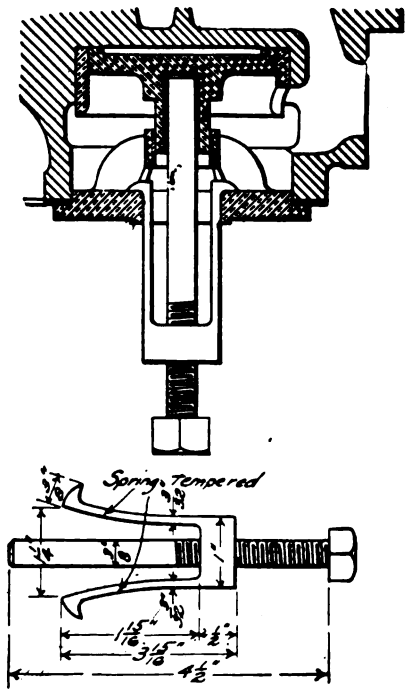


Fig. 11

not attempt to lengthen it by pulling out the coils.

Check Valves.—The check valve should be absolutely tight on its seat, and, if necessary,

the seat should be renewed or reamed. A reamer for this purpose is shown in Fig. 13. With old valves having cast-iron seats worn down below the limit, the check valve case should be bored out and a brass seat put in. In doing this it must be remembered that this seat must make an air tight joint with the check valve case, and when in place should be standard. The check valve should be ground to a good joint.

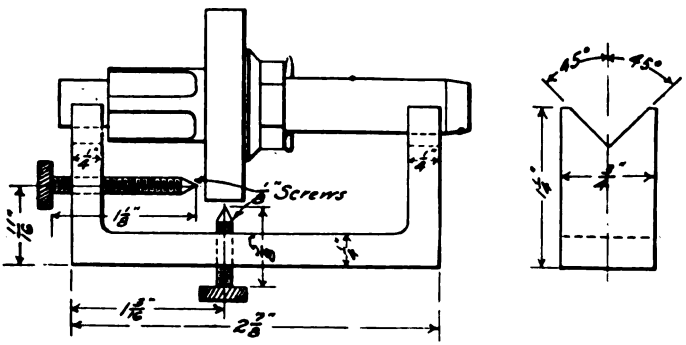


Fig. 12

Check Valve Case Gasket.—Generally speaking it will be better and cheaper in the long run to renew the check valve case gasket than to use the old one again, as it is only a question of time when the old gasket will blow out.

Assembling.—Before assembling the valve it should be thoroughly blown out. All bolts and nuts should be examined to see that they are not cracked, and that the threads are in good condition. Before applying gaskets the

parts they come in contact with should be thoroughly cleaned, and if graphite is used on the face of the gaskets there will be no trouble with their sticking when the valve is next

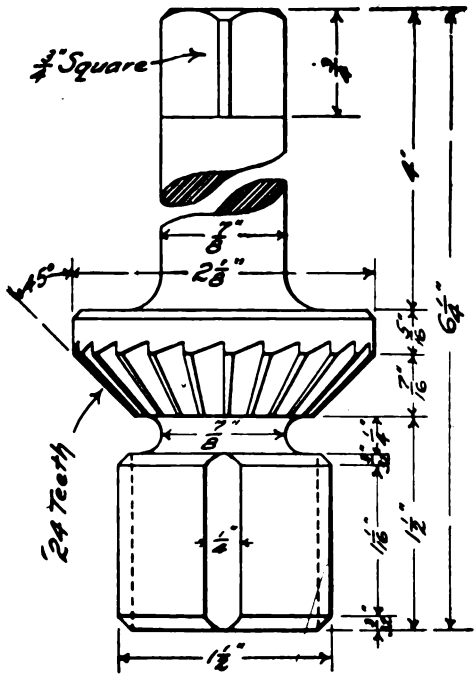


Fig. 13

taken apart. Difficulty is sometimes experienced in getting the check valve case to draw up close to the valve body on account of the recess in which the emergency valve seat rests not being properly cleaned out so that the seat

will fully enter. In applying the check valve case, hold it firmly to its seat until both cap screws have been brought to a bearing, and then draw them up with a wrench as uniformly as possible in order to prevent the cocking of the case. *No oil or grease of any kind should be used on the emergency parts.*

New York Triple Valves. To dismantle a New York quick action triple valve proceed as follows (see Fig. 14).

Remove the three front cap bolts 135 and then the front cap 126, being careful not to destroy the front cap gasket 134. Next remove the vent valve seat 130, to which is attached the vent valve piston 129. Then remove the two piston stop screws (not shown in the cut), the piston stop 142, and remove the vent valve piston and place in the kerosene tank. Next remove the main piston 128, to which the exhaust and graduating valves are attached, placing it in the kerosene. Next remove the quick action valve cap 141, take out the quick action valve 138 and note its condition. The rubber seat 20 generally needs renewing. Next remove the check valve cap 119, and examine the check valve 117 and its seat. This valve must be perfectly tight and should be ground in if necessary. Next examine the vent valve 131 and renew the rubber seat 20 if needed. This seat needs renewing very often, as from the construction the pressure of the spring is greater on the bottom part of the seat than on the top, which

very soon distorts the seat. Next remove the side cap 127 and the quick action valve piston 137. The piston and cylinder should be thoroughly cleaned before replacing. The valve body and all ports should be thoroughly cleaned out by means of an air blast, and the main piston cylinder wiped out with rags, paying particular attention to the feed groove *B*. The small port *F* in the vent piston 129 should be cleaned out, using care that the size of the port

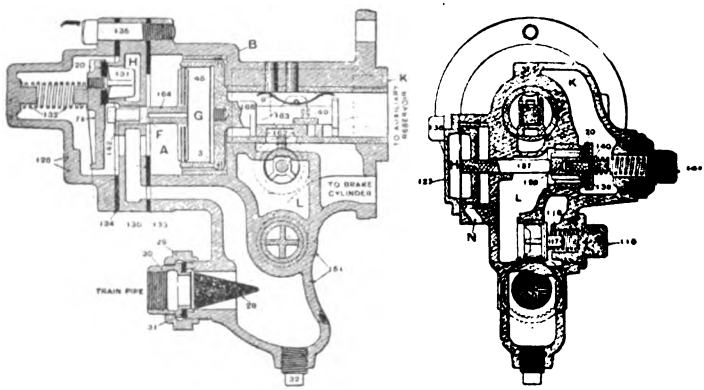


Fig. 14

is not increased, as on this port depends the quick action feature of the valve. The plug in the end of the vent piston should not be removed except to fit a new vent piston packing ring 45. This packing ring should be fitted, when necessary, in exactly the same manner as was described for fitting the packing ring in the Westinghouse triple, and after fitting, the plug should be replaced, for if it is left out it will

destroy the quick action feature of the valve. The same instructions as were given for the Westinghouse valves apply as to the fitting of the main piston packing ring 3 and the facing of the exhaust valve 38 and the graduating valve 49. If the exhaust valve 38 is removed from the stem, be careful in replacing it that the long shoulder of the valve is placed next to the graduating valve 49. *This is very important* as the exhaust cavity in the valve is not in the center of the valve length, and if the valve is placed in position incorrectly, the brake cylinder will always be in communication with the atmosphere and it would be impossible to set the brake. The main cylinder gasket should not be scraped but it should be well cleaned. The vent valve piston should be tested to see that the stem is true, after which it should be placed in the seat and secured by applying the stop 142 and securing the two stop screws firmly.

In assembling the valve a few drops of good oil should be applied to the graduating valve, exhaust valve, and on the packing rings in the main piston and vent valve piston, and the surface of the cylinders sparingly oiled. Place the main piston and valves in position; then place the vent valve piston and seat in position and bolt on the front cap. Replace the quick action valve and cap, then the quick action valve piston, observing that the piston moves freely. Replace the check valve and cap, and the valve is ready for the testing rack.

Testing Repaired Triple Valves.—Fig. 1 shows a vertical section and Fig. 2 a plain view of a testing rack for repaired triple valves.

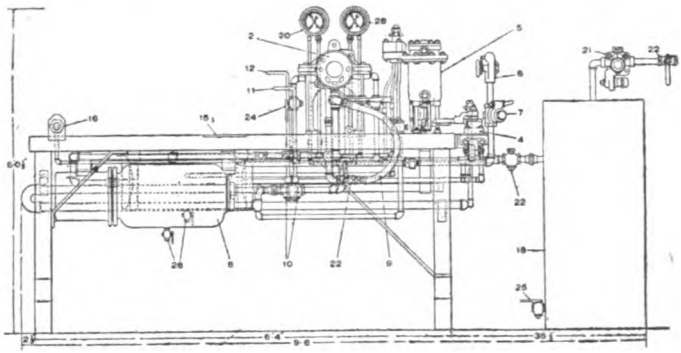


Fig. 1
Test Rack.

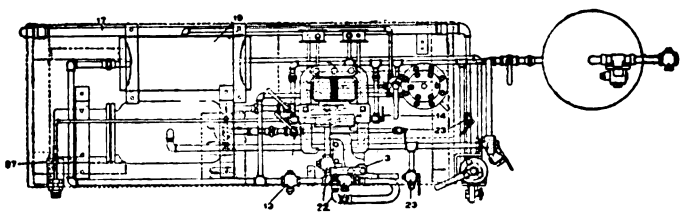


Fig. 2
Test Rack (Plain View).

LIST OF PARTS.

2, Triple Valve Stand; 3, Brake Pipe Clamping Device (see also Fig. 3); 4, Brake Valve with Graduating Disc Valve; 5, Differential Valve; 6, Variable Choke Valve; 7, Combination Cock 6 and Quick Opening Valve; 8, Dummy Cylinder and Reservoir; 9, ¾"x26" Hose with two threaded Nipples for ¾" Pipe; 10, ¾" Cut-out Cocks; 11, 17⅛" Extension Handle for Cut-out Cock; 12, 20⅛" Extension Handle for Cut-out Cock; 13, ¾" Cut-out Cock with side vent; 14, ½" Cut-out Cock with side vent; 15, Assembling Plate; 16, Bracket for Cock Tester; 17, Reduction Measuring Reservoir; 18, Main Reservoir; 19, 10"x24" Reservoir; 20, Duplex Air Gauge; 21, C-6 Single Pressure Feed Valve; 22, ¾" Cut-out Cock; 23, ½" Cut-out Cock; 24, ½" Cut-out Cock;

25, ½" Reservoir Drain Cock; 26, ¼" Reservoir Drain Cock; 27, ¼" Cut-out Cock; 28, Duplex Air Gauge.

Fig. 4 shows diagrammatically the parts comprising the Triple Valve Test Rack. The letters and numbers shown on this cut are the ones hereinafter referred to.

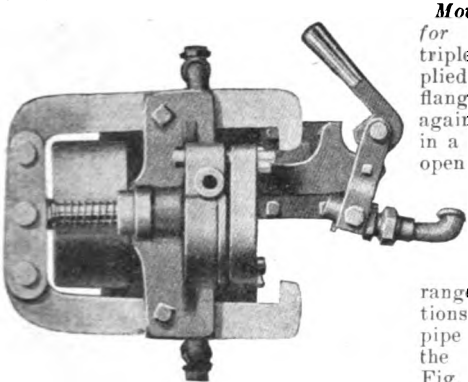


Fig. 3

Brake Pipe Clamping Device.

Mounting Triple Valves for Testing.—With the triple valve gasket applied to the triple valve flange, place the latter against the testing stand in a vertical position and open cock X (Fig. 4). If the triple valve to be tested is of the pipeless type, open cock Y. If it is of the type arranged for pipe connections, connect the brake pipe to the triple with the clamping device, Fig. 3, then open cock Z. One of the other of these two cocks must always be closed and the other open while the triple valve is on the stand for test.

The shoe attached to the hook portion of the hose clamping device is for use only when testing other than Westinghouse triple valves. It is very important that the shoe always be used when testing such triples, as a failure to do so will prevent the clamp hook coming in contact with the check valve case, causing all the strain of forcing the hose gasket against the brake pipe connections of the triple valve to be imposed on the clamp stand, tending to distort or break it.

Four triple valve stand face plates are required for each test rack to permit the testing of all types of triple valves.

Plate No. 1 is used for triple valves which have a bolted flange, viz.: H-1 (F-36), P-1 (F-27), K-1, L-1, M-1 and R-1 triple valves. Plate No. 2 is for triple valves, including H-2 (H-49), P-2 (F-29), K-2, L-2, M-2 and R-2. Plate No. 3 is for L-3 and R-3 triple valves only. Plate No. 4 is for plain triple valves supported upon a pipe nipple and for safety valves, also, for testing the triple valve test rack.

If it is found necessary to repeat any test which has necessitated a reduction of auxiliary reservoir pressure, valve B may be moved to position No. 2, which provides a by-pass around the triple valve from the brake pipe to the auxiliary reservoir, thereby permitting a quick recharge.

By keeping the stuffing box nut sufficiently tight the spring of lever D will hold the lever in any position on its quadrant, thereby preventing any leakages at the stuffing box in the bottom of the differential valve.

Test No. 1.—Charging Test for all Triple Valves.—With cocks 2, 3, 7, and 9 open, all other numbered cocks closed, valve B in position No. 3 (Lap), valve A in position No. 1, auxiliary reservoir empty and main reservoir pressure 80 lbs., proceed as follows:

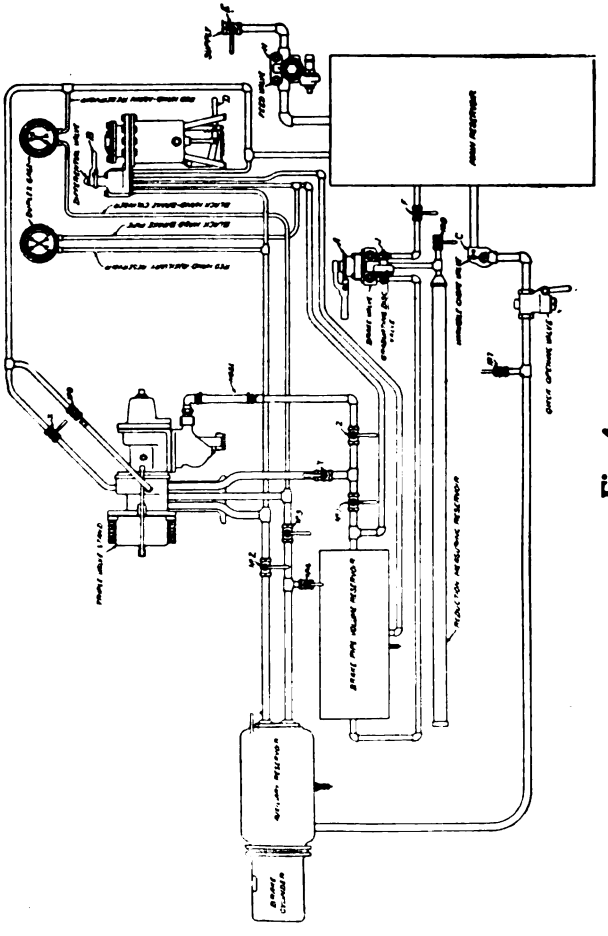


Fig. 4

Diagrammatic View of the Parts of the Triple Valve Test Rack.

Close cock 7 and open cock 1, and note, with brake pipe pressure maintained at 80 lbs., the time required by the various triple valves to charge the auxiliary reservoir to the pressure given in the table below.

If, during this test or test No. 2, any considerable leakage is discovered, the charging test must be repeated.

TIME LIMITS FOR CHARGING WITH DIFFERENT TYPES OF WESTINGHOUSE TRIPLE VALVES.

Type of Triple Valve	Time in seconds to Charge Auxiliary Reservoir from 0 to 30 lbs.	Time in seconds to Charge Auxiliary Reservoir from 0 to 70 lbs.
F-24	13 to 17	34 to 44
G-24	13 to 17	34 to 44
F-25		16 to 25
F-1	13 to 17	34 to 44
F-2		16 to 25
H-1 (F-36)	21 to 28	58 to 78
H-2 (H-49)	13 to 17	34 to 44
P-1 (F-27)	13 to 17	34 to 44
P-2 (F-29)		16 to 25
M-1		16 to 20
M-2-A		12 to 15
R-1		18 to 22
R-2		12 to 15
L-1-B		20 to 26
L-2-A		12 to 15
L-3		9 to 11
K-1	32 to 42	100 to 120
K-2	19 to 24	60 to 72

Test No. 2.—Leakage Tests.—With cocks 1, 2, 3 and 9 open, all other numbered cocks closed, valve B in position No. 3 (Lap), valve A in position No. 1, and auxiliary reservoir charged to 80 lbs., proceed as follows:

A.—Leakage at Exhaust in Emergency; Check Valve and Cylinder Cap Gasket Leakage.—Operate the triple valve, two or three times in quick action, by closing and opening cock 1; finally leaving it closed.

Coat the exhaust port of triple valve with soap suds to ascertain if leakage exists past the slide valve or bushing to the exhaust, with the piston and slide valve in emergency position. Close cocks 2 and 3 and note the rate of fall of pressure indicated by the brake cylinder gauge, which is now connected only with the small volumes between cocks 2 and 3 and the triple valve. A

leakage greater than 5 pounds in 10 seconds indicates either excessive check valve leakage or that the piston does not seal against the cylinder cap gasket.

At the completion of this test, open cocks 2 and 3 in the order given.

B.—Leakage at Exhaust in Release; Slide Valve or Emergency Valve Leakage.—Open cock 1 and after the brake cylinder pressure is exhausted, close cock 3 and again coat the exhaust port with soap suds to determine if there is any leakage from the auxiliary reservoir to the brake cylinder past the slide valve when the triple valve is in release position, or from the brake pipe to the brake cylinder past the emergency valve or its seat when the differential on the emergency valve is high. Open cock 3, then paint the body of the triple valve with soap suds to determine if leakage exists direct to the atmosphere through castings or gaskets.

If leakage is discovered at the triple valve exhaust in release position, determine if it is from the auxiliary reservoir past the seat of the slide valve or from the brake pipe past the emergency valve in the following manner:

Move valve A to position No. 8 and open cock 7 until the brake pipe and auxiliary reservoir are empty; then, with valve J in position No. 3, place a soap bubble on the exhaust port and place valve A in position No. 2. If under these conditions no leakage is found at the exhaust, advance valve J by stages from position to position until a brake pipe pressure of 10 lbs., is obtained, and again note if there is leakage from the exhaust.

Any leakage at the exhaust, while the auxiliary reservoir is without pressure, must be from the brake pipe past the emergency valve therefore, if no exhaust leakage is found and leakage did exist while the auxiliary reservoir was charged, it indicates a defective slide valve.

At the completion of the test, close cock 7 and move A to position No. 1, recharging the auxiliary reservoir.

C.—Graduating Valve Leakage.—Move valve A to position No. 7 until a brake cylinder pressure of 20 to 30 lbs. is obtained. Then return valve A to position No. 3 and close cock 3. If the brake cylinder pressure then increases without leakage at the exhaust port, it is proper to assume that the graduating valve is leaking, providing it has been determined by the preceding tests that the emergency valve is tight. If leakage at the exhaust occurs during this test, which will be determined by placing a soap bubble on the exhaust, the leakage may be either slide valve or graduating valve leakage. The rate of pressure on the brake cylinder gauge, resulting from graduating valve leakage, must not exceed 5 lbs., in 20 seconds. This comparatively rapid rate of rise is permissible owing to the extremely small volume of the section of brake cylinder pipe into which the leakage is occurring.

At the completion of the test, open cock 3 and move valve A to position No. 1.

Test No. 3.—Test of Type "K" Triple Valve for the Retarded Release Feature.—With cocks 1, 2, 3 and 9 open, all other numbered cocks closed, auxiliary reservoir charged to 80 lbs., valve B in position No. 3 (lap), lever D in notch No. 2 and valve A in position No. 3, proceed as follows:

Move valve A to position No. 7 until brake pipe pressure is reduced 20 lbs., then return it to position No. 3, place valve J in position No. 4; valve B in position No. 1 and valve A in position No. 2. This should move the triple valve parts to normal (full release) position.

If the triple valve moves to retarded release position, which is indicated by a contracted exhaust and slow release of brake cylinder pressure, it indicates a weak or broken retarded release spring, or undue friction in the retarding device.

Following this test recharge the system to 80 lbs., by moving valve A to position No. 1 and valve B to position No. 2.

When the brake pipe and auxiliary reservoir are charged to 80 lbs., move valve *A* to position No. 7 until brake pipe pressure is reduced 20 pounds, then return it to position No. 3. Place valve *J* in notch No. 8, lever *D* in notch No. 4, valve *B* in position No. 1, and valve *A* in position No. 2.

Under these conditions the triple valve piston and slide valve should be forced to retarded release position. If this does not occur it indicates that the retarded release spring is not standard or the retarding device has excessive friction.

At the completion of the test place valve B in position No. 3, and valve A in position No. 1.

Test No. 4.—Application Test.

A.—Service Sensitiveness.—If for any reason, it is desired to make this test following an application and release produced by closing and opening cock 1 or the auxiliary reservoir has just been charged by opening cock 1, this test should be preceded by an application and release with valve A, for the purpose of insuring the slide valve being in its normal position.

Commencing the test with cocks 1, 2, 3 and 9 open, all other numbered cocks closed, valve A in position No. 1, valve B in position No. 2 and lever D in suitable notch for the triple valve under test, which is: Notch No. 3 for H-1, H-2, K-1, K-2, and notch No. 4 for F-24, F-25, G-24, F-1, F-2, P-1, P-2, L-1-B, L-2-A, L-3, M-1, M-2, R-1, R-2. Then with the auxiliary reservoir charged to 80 lbs., proceed as follows:

To test H-1 and K-1 triple valves, place valve B in position No. 4 and valve A in position No. 5.

To test K-2, L-1-B, L-2-A, L-3, M-1, M-2, R-1, R-2, H-2, P-1, F-1, G-24 and F-24 triple valves, place valve B in position No. 4 and valve A in position No. 6.

To test P-2, F-2 and F-25 triple valves, place valve B in position No. 4 and valve A in position No. 7.

In preparing to test F-1 and F-2 triple valves place valve A in position No. 3, valve B in position No. 2, and open cock 7 until the auxiliary reservoir and brake pipe pressure is reduced to fifty pounds. To test F-1 triple valves, place valve B in position No. 4 and valve A in position No. 6. To test F-2 triple valves, place valve B in position No. 4 and valve A in position No. 7.

In all of these tests the triple valve should move to application position without causing a discharge of air from the vent port of valve B.

A failure to apply under the conditions specified indicates either excessive friction, which will be shown by an exhaust from the vent port of valve B; a leaky packing ring, which will be discovered later by the packing ring, leakage test, too large a feed groove in the cylinder, or a combination of two or more of these defects. Should the triple valve fail to apply and no exhaust occur from valve B, the indications are that the back flow of air from the auxiliary reservoir to the brake pipe is too rapid to permit the required differential.

At the completion of this test, move valve B to position No. 3 and valve A to position No. 1.

B.—Quick Service Test (For Quick Service Triple Valves Only). —With cocks 1, 2, 3 and 9 open, all other numbered cocks closed, valve A in position No. 1, valve B in position No. 3 and auxiliary reservoir charged to 80 lbs., proceed as follows:

Close cock 9 and move valve A to position No. 7 for all No. 1 and No. 2 triple valves and position No. 8 for all No. 3 triple valves. The brake cylinder pressure obtained should not be less than 5 lbs., greater than that which will be obtained by subjecting to the same test triple valves which do not contain the quick service features.

At the completion of this test, move valve A to position No. 1 and open cock 9.

Test No. 5.—Packing Ring Leakage.—Release Test.—Sec. 1.—With cocks 1, 2, 3 and 9 open, all other numbered cocks closed, valve A in position No. 1, valve B in position No. 3, and the auxiliary reservoir charged to 80 lbs., proceed as follows:

Place the valve A in position No. 7 until the brake pipe pressure is reduced 15 pounds, then return to position No. 3 (Lap). Place valve J in position No. 2, lever D in notch No. 1, and valve B in position No. 1; close cocks 2 and 3, and move valve A to position No. 2. If the discharge does not occur promptly from the vent port of valve B advance valve J from position to position until the discharge begins, then note the rate of increase of pressure on the auxiliary reservoir gauge.

Packing ring leakage will be indicated on this gauge and must not exceed 5 lbs., in 30 seconds.

During this test there must be a steady exhaust of air from the vent port of valve B to insure the proper differential being maintained on the triple valve piston The triple valve must not release during this test. If it does, the test is void, and must be repeated.

Should it happen that the friction is so low as to continue to permit the triple to release, the reduction for the application may be changed from 15 to 10 lbs. When this is done special attention should be given to determining if the graduating valve is tight.

At the completion of this test, place valve B in position No. 3; open cocks 2 and 3 and place valve A in position No. 1.

Test No. 6.—Friction Test.—Release Test.—Sec. 2.—With cocks 1, 2, 3 and 9 open and all other numbered cocks closed, valve A in position No. 1, valve B in position No. 3, auxiliary reservoir charged to 80 lbs., for all triple valve excepting F-1 and F-2.

To test F-1 and F-2 triple valves place valve A in position No. 3, valve B in position No. 2, and open cock 7 until the auxiliary reservoir and brake pipe pressure is reduced to fifty pounds, then place valve B in position No. 3.

Place lever D in the proper notch for the triple valve undergoing the test, that is:

Notch No. 3 for H-1, H-2, K-1, K-2 triple valves and notch No. 4 for F-24, F-25, G-24, F-1, F-2, P-1, P-2, L-1-B, L-2-A, L-3, M-1, M-2, R-1, R-2 triple valves, proceed as follows:

Place valve A in position No. 7 until the brake pipe pressure is reduced 10 pounds, then return it to position No. 3. Place valve J in position No. 1, valve B in position No. 1, and move valve A to position No. 2. A failure to release under these conditions should be accompanied by a discharge at the vent port of valve B, which indicates that the frictional resistance to the movement of the packing ring and slide valve is excessive.

If the triple valve does not release and valve B fails to open its exhaust, leakage is occurring from the brake pipe which will necessitate advancing valve J from position to position, remaining in each position 30 seconds, until the triple valve releases or the exhaust in valve B opens.

At the completion of the test, place valve B in position No. 3 and valve A in position No. 1.

As the F triple valve is always located adjacent to the brake valve and source of air supply, somewhat less severe friction test is permissible.

Test No. 7.—Service Port Capacity Test.

A.—With cocks 1, 2, 3, 4 and 9 open, valve A in position No. 1, valve B in position No. 3, place valve C in position required for the triple valve under test, as indicated: Notch No. 1—H-1, K-1. Notch No. 2—K-2, H-2, M-1, R-1. Notch No. 3—L-1-B, P-1. Notch No. 4—M-2-A. Notch No. 5—P-2. Notch No. 6—L-2-A, R-2. Notch No. 7—L-3.

During this test the brake pipe pressure should not drop, except that in the case of the quick-service triple valves there will, of necessity, be a slight drop, which must not exceed two pounds.

Place valve B in position No. 2 and move valve A to position No. 3, open cock 7 until brake pipe and auxiliary reservoir pressures are reduced to 50 pounds, then close cock 7. Move valve B to position No. 3 and open combination cock 6 and quick opening valve, leaving it open 3 seconds. If this test produces quick action it indicates a restriction in the service port or a weak graduating spring.

B.—Duplicate the tests specified under Sec. A, placing the wheel of valve C in the position as indicated: Notch No. 3—H-1, K-1. Notch No. 4—R-1. Notch No. 5—L-1-B, M-1, K-2, P-1. Notch No. 6—M-2-A. Notch No. 7—P-2, R-2, L-2-A, H-2. Notch No. 9—L-3.

Failure of the triple valve moving to emergency position indicates too loose a fit of the emergency piston.

At the completion of the test close cock 4 and combination cock 6 and quick-opening valve and move valve A to position No. 1.

Test No. 8.—By-Pass Valve, Safety Valve and Graduated Release Tests.—With cocks 1, 2, 3 and 9 open, all other numbered cocks closed, valve A in position No. 1, valve B in position No. 3 and auxiliary reservoir charged to 80 lbs., proceed as follows:

A.—By-Pass Valve Test.—Open cock 8; move valve A to position No. 7 until the brake pipe pressure is reduced 10 lbs., and return it to position No. 3; then close cocks 2 and 3, and note if brake cylinder pressure increases. If so, close cock 8, which will stop the increase in cylinder pressure if caused by a defective valve seat.

At the completion of this test, open cocks 3 and 8, if closed, and move valve A to position No. 1.

B.—Safety Valve Test.—Place valve A in position No. 7 until a brake cylinder pressure of 10 to 20 lbs. is obtained; then return valve A to position No. 3. Place valve C in notch No. 10 and open combination cock 6 and quick-opening valve; rotate valve C until main reservoir air flows through it to the auxiliary reservoir, the amount of opening necessary being only sufficient to get a slow increase of brake cylinder pressure, then observe the brake cylinder gauge and note the pressure at which the safety valve opens and closes. The safety valve should be adjusted to open at 62 pounds and close at 58 pounds. The range of the safety valve is regulated by increasing or decreasing the discharge ports from the spring chamber by means of the regulating ring. At the completion of the test, close combination cock 6 and quick-opening valve, paint the safety valve with soap suds, to determine if there is any leakage in the safety valve or in the joint between it and the triple valve. On completing this test, place valve A in position No. 1.

C.—Graduated Release Test.—With cock 8 open, move valve J

to position No. 7. Place valve A in position No. 7 until a brake cylinder pressure of 40 lbs. has been obtained. Then place it in position No. 2 until the triple valve moves to release position, after which, return it immediately to position No. 3. When the triple valve exhaust closes, due to the graduated release action, move valve A from position No. 3 to position No. 2, and back to position No. 3. If the triple valve has the required sensitiveness for graduation of the release, it will close the exhaust almost simultaneously with the movement of the handle of valve A from position No. 2 to position No. 3. At least four release graduations should be obtained before the cylinder pressure is entirely exhausted.

A failure to obtain the required number of graduated release operations indicates either a restriction of the supplementary reservoir opening through the triple valve to the auxiliary reservoir, or frictional resistance to the movement of the triple valve piston and slide valve. At the completion of the test, move valve A to position No. 1, and close cock No. 8.

Maintenance of Test Rack.—Cleaning and Lubrication.—Once each week the rotary valve in valves A and B should be lubricated with oil and the cock keys removed, cleaned and lubricated. The clamping cylinder and its packing leather should be lubricated with brake cylinder lubricant. The rotary discs in valves C and J should be lubricated very sparingly with oil and with sufficient frequency to make them easy to operate. Metal instruments should not be used for cleaning the disc openings on account of enlarging them and increasing the rate of feed.

The piston in the valve body of combination cock 6 and quick-opening valve should be cleaned occasionally and very sparingly lubricated with oil or graphite grease.

Installation and Maintenance of the Differential Valve.—The weight chamber of the differential valve must stand vertical to prevent friction which will result from the weights hanging out of center. It may be leveled up by adjustment of the nuts on three studs by which it is attached to the table.

To determine if it is level, remove the plugs from two sides of the weight chamber near its bottom; then, starting with lever D in position No. 4, raise it until the table on the upper end of the rod attached to lever D comes in contact with the lower weight, which may be seen through the openings provided. If the table strikes square on the bottom of the weight the differential valve is level.

Before reassembling the diaphragm and weight section of the differential valve, after having been taken apart for any purpose, the length of the exhaust valve stem should be so adjusted by screwing it into or out of the spool which carries the exhaust valve as to make the dimension between the punch marks on the side of the upper end of the stem and the upper end of the spool 1⅝ inches.

Testing the Rack for Leakages.—When preparing to test the rack for leakage, place plate No. 2 on the stand and clamp to it, using suitable gaskets, plate No. 4, the pipe openings in which have been closed with plugs. Close cocks 8 and Z and combination cock 6 and quick-opening valve.

Move valve A to position No. 1, which will connect the main reservoir to the brake pipes. Move valve B to position No. 2, which will connect the brake pipe and the auxiliary reservoir through the differential valve. When the brake pipe and auxiliary reservoir pressures have been raised to 70 pounds move valve A to position No. 3 (Lap), which cuts off the supply to brake pipe, and move valve B to position No. 3 (Lap), which cuts off all communication between the brake pipe and auxiliary reservoir. Brake pipe pressure is now in the reservoir and the pipes connected to the brake valve, triple valve stand, brake pipe gauge and differential valve. Valve B being in position No. 3 also gives brake pipe pressure both above and below the diaphragm. If the brake pipe pressure indicated by the duplex gauge falls, it indicated leakage to the atmosphere from the piping or some of the appliances subjected to brake pipe pressure. Leakage may be located by coating the pipe fittings, joints and devices with soap suds. Special care must be exercised to prevent leakage through the stuffing box on the differential valve. If cock 9, which is the brake pipe exhaust cut out cock, is open and will not hold a bubble, the rotary of valve A is leaking.

If while making the test the brake pipe pressure increases there is leakage from the main reservoir to the brake pipe and as main reservoir pressure is on top of the rotary valve of valves A and B only, one of these valves is leaking. To determine which, disconnect the union connection of the brake pipe to valve A, then with valve A in position No. 3 place a soap bubble on its brake pipe connection. If found to be tight the rotary valve leakage is in valve B.

If pressure indicated by the auxiliary reservoir gauge falls, it indicates leakage from the auxiliary reservoir, auxiliary reservoir piping, or some of the apparatus attached thereto. One pipe is connected to combination cock 6 and quick-opening valve, one to the triple valve stand, one to the gauge, and one to the differential valve. The leakage can be located by the use of soap suds.

Immediately following this test, close cock 2 and note if there is any drop in pressure, and if so, it should be corrected. At the completion of the test open cock 2.

If the pressure indicated by the auxiliary reservoir gauge increases, main reservoir pressure is leaking into the auxiliary reservoir (or its pipe connections when cock 2 is closed), either past the rotary of valve B or past the seat of combination cock 6 and quick-opening valve. To determine which, after exhausting all the air from the auxiliary reservoir, close cock 2, and with cock 7

open, place a soap bubble on it. If leakage is found at cock 7 the seat of the quick-opening valve is leaking; if not, the rotary of the differential valve B is leaking.

To determine if there is leakage from the brake pipe to the auxiliary reservoir, or the reverse, place valve A in position No. 1 and valve B in position No. 2 until the auxiliary reservoir is charged to 70 pounds; then move valve B to position No. 3 and valve A to position No. 8. This will exhaust all brake pipe air. Close cock 2 and if the leakage exists between the brake pipe and the auxiliary reservoir, the auxiliary reservoir pressure will drop. This can be caused either by leakage between the ports of the rotary valve B or a porous casting in the triple valve stand, or differential valve.

To test cock 2 for leakage charge the auxiliary reservoir to 70 lbs., then place valve B in position No. 3, close cock 2 and open cock 7. If the auxiliary reservoir pressure falls cock 2 is leaking.

To test for a ruptured diaphragm in the differential valve, place valve A in position No. 1 and valve B in position No. 2. When the brake pipe and auxiliary reservoir pressures have been raised to 60 pounds move valve A to position No. 3 (Lap). Move valve B to position No. 1, which will separate brake pipe and auxiliary reservoir pressures, brake pipe pressure being under the diaphragm and auxiliary reservoir pressure above it. Place lever D in position No. 4, which will suspend all the weights from the diaphragm and permit an increase of brake pipe pressure 4 pounds higher than that in the auxiliary reservoir. To do this place valve A in position No. 2, valve J in position No. 5, and close cock 2. When this difference in pressure has been obtained a strong exhaust should follow from the vent port of the differential valve and the auxiliary reservoir pressure should remain stationary. If this pressure increases (the rotary valve of the differential valve B having already been tested) the diaphragm is defective.

To test the exhaust valve of the differential valve place the handle of valve B in position No. 3 and valve A in position No. 1. If the exhaust valve is tight there will be no leakage from the exhaust port.

If the rotary disc seat in valve J becomes defective it can permit leakage from the main reservoir to the atmosphere brake pipe to the atmosphere or, when it is in use for controlling the rate of feed, main reservoir to brake pipe. Leakage to the atmosphere can be detected by placing soap suds around the stem between the hand wheel and valve body. To detect leakage from the main reservoir to the brake pipe, charge the brake pipe to 70 pounds, place valve J in position No. 2, and valve A in position No. 2. Under these conditions the brake pipe pressure should not increase more than 7½ pounds in one minute. The orifices in the rotary disc of valve J should be examined occasionally to make certain that they are not obstructed.

To test cock 1 for leakage charge the brake pipe to 80 pounds, close cock Y, close cock 1 and open cock Z. Cover the vent opening in cock 1 and place a soap bubble on the opening in the brake pipe clamp.

To test cocks Y and Z for leakage charge the brake pipe to 80 lbs., close cocks Y and Z, open cock 1 and place a soap bubble on the opening in the brake pipe clamp to test cock Z, and on the brake pipe openings in the face of the triple valve stand to test cock Y.

To test cock 3 for leakage apply a triple valve to the stand and charge the brake pipe and auxiliary reservoir to 80 lbs. After closing cock 3 place valve A in position No. 7, open cock 4 and place soap bubble upon it.

CHAPTER XVIII.

ERECTING SHOP WORK—INTERNAL COMBUSTION ENGINES.

The internal combustion engine, or gas engine as it is commonly called, is becoming quite common in railway work, being used extensively for pumping water and for operating the machinery of coal chutes. It is also being gradually introduced as the motive power for single cars for use upon branch lines where the traffic is light. This being the case it is necessary for the railway machinist, if he is to be "up-to-date," to secure a working knowledge of this form of motor.

The term internal combustion engine includes gasoline engines, kerosene engines, crude oil engines, and alcohol engines, as well as those that run on either city gas, producer gas, or natural gas.

The general principles governing both the construction and operation of an internal combustion engine are nearly the same as in a steam engine, the object in both being to obtain useful work from heat, that is, to transform heat energy into work.

In the steam engine the fuel is burned in the fire box of the boiler, the heat of combustion converting the water into the gas called steam. By means of suitable pipes the steam is conveyed

to the engine where its expansive force is made use of to push the piston back and forth and rotate a shaft from which the power is taken off by suitable means. In the case of the internal combustion engine the transformation of heat into work is accomplished in a more direct manner. The fuel, together with the required amount of air for combustion, is introduced directly into the engine cylinder where it is burned. The gases, or smoke, resulting from this combustion of the fuel are raised to a very high temperature and this increase in temperature causes the gases to expand and thus provides the force for moving the piston.

From the foregoing comparison it will be seen that the internal combustion engine combines in one machine the engine, boiler and fire-box of the steam plant, and hence should be more efficient, that is, the same amount of heat developed should produce a greater amount of useful work, and as a matter of fact it does. The average steam engine will turn from five to ten per cent of the heat energy of the fuel into useful work at the crank shaft, while an ordinary internal combustion engine will deliver from twelve to twenty-five per cent.

Practically all of the internal combustion engines now built operate on what is known as the Otto cycle which requires two revolutions of the crank shaft and four piston strokes to complete the various operations. There are also engines built which use a modification of this cycle in which a portion of the necessary

operations are carried on in a separate device, or its equivalent, in order to permit the operations to be completed during one revolution of the crank shaft. The above mentioned differences in construction divide internal combustion engines into two types commonly known as *four cycle engines* and *two cycle engines.*

Taking up the first type, the series of operations which take place during the four piston

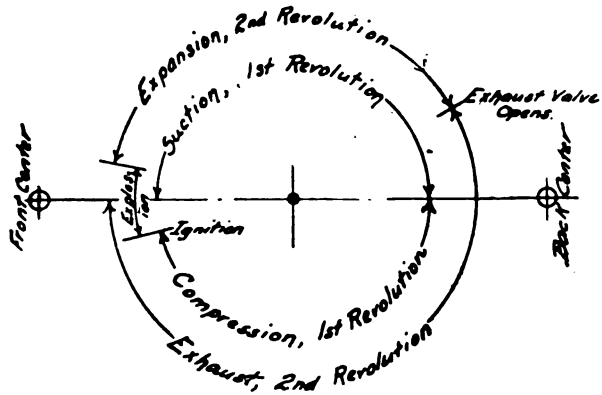


Fig. 1

strokes necessary to complete the cycle are as follows: During the *first outward stroke* of the piston a mixture of gas and air, called the charge, is drawn into the cylinder through the inlet valve. During the *first inward stroke* of the piston this charge is compressed into the clearance space at the end of the cylinder. Just before the piston reaches the end of this compression stroke, the charge is ignited and the

ensuing explosion causes a sudden increase of pressure due to the heat developed by the combustion of the gas. The expansion of these heated gases drives the piston on the *second outward stroke.* Just before the piston reaches the end of this stroke, the exhaust valve is opened, permitting the contents of the cylinder to escape to the atmosphere. The *second inward stroke* clears the cylinder of the burnt gases, the exhaust valve being held open until the end of the stroke. The cycle given in tabular form is as follows:

First Revolution	Outward stroke: Suction. Inward stroke: Compression, ignition, explosion.
Second Revolution	Outward stroke: Expansion, release. Inward stroke: Exhaust.

This will be made clear by an inspection of Fig. 1, which shows the sequence of events as they occur during the two revolutions of the crank.

Referring to Figs. 2 and 3, the operation of the two cycle engine will be described. In this engine, as was before mentioned, there must be a separate device for performing part of the operations. This takes the form of a compression chamber which may be a separate cylinder, or the front end of the power cylinder, or the enclosed crank case. A majority of the engines of this type use the enclosed crank case, hence this type will be described. Referring to

Fig. 2, the chamber *A*, enclosing the crank, is built gas tight. Starting with the piston at the bottom of the cylinder let it make an up stroke. This will tend to produce a vacuum in the crank case and a charge will enter through the inlet valve *a* and fill the case. As the piston makes

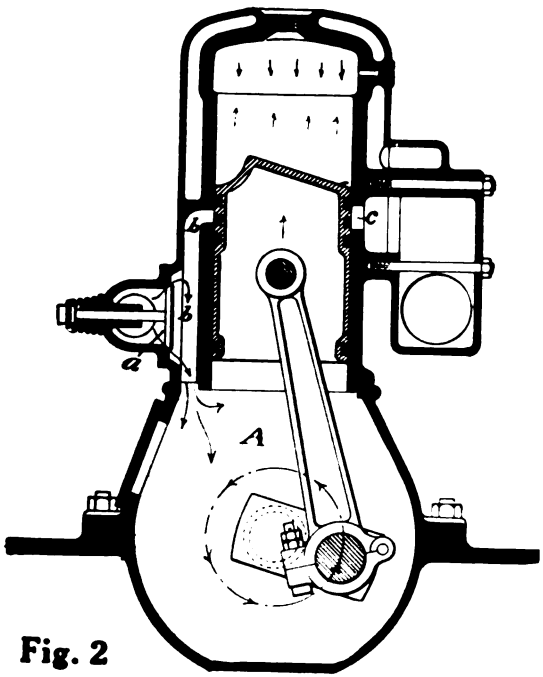


Fig. 2

the down stroke it will compress the charge in the crank case until the piston travels down far enough to open the inlet port *b*, Fig. 3. The cylinder and crank case now being in communication, the compressed charge rushes into

the cylinder. As the piston starts on the second up stroke, the port *b* is closed, and the charge, now in the upper end of the cylinder, is compressed and at the same time a new charge is being taken into the crank case. When the

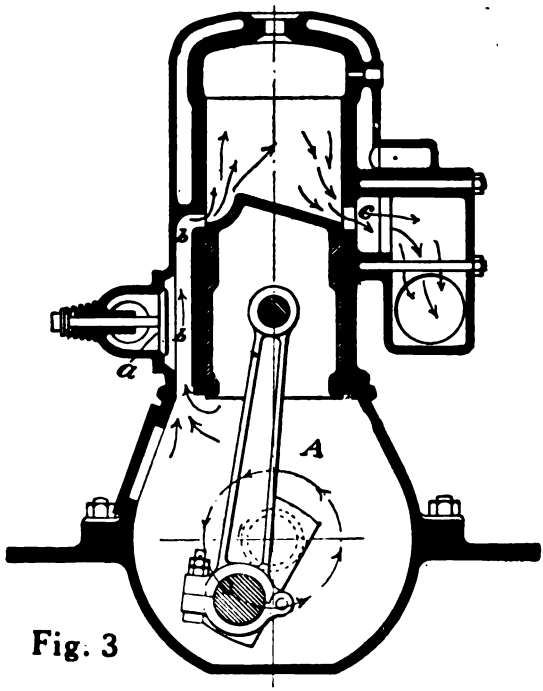


Fig. 3

piston reaches the end of the second up stroke, ignition takes place and the resulting expansion forces the piston to make the second down stroke, which of course compresses the charge in the crank case. As the piston reaches the bot-

tom of the cylinder it uncovers the exhaust port *c*, Fig. 3, allowing the burnt gases to escape to the atmosphere, and also opens the inlet port *b*, and a new charge goes into the cylinder. Thus it will be seen that with this type of engine the

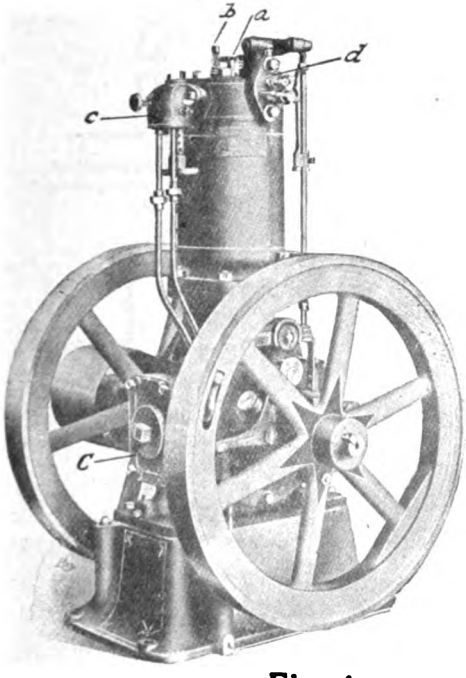


Fig. 4

piston receives an impulse every revolution of the crank shaft instead of one every two revolutions, as is the case with engines of the four cycle type.

The two cycle engines are rarely used for stationary work, but on account of their developing more power in proportion to weight and size, they are extensively used for automobiles and

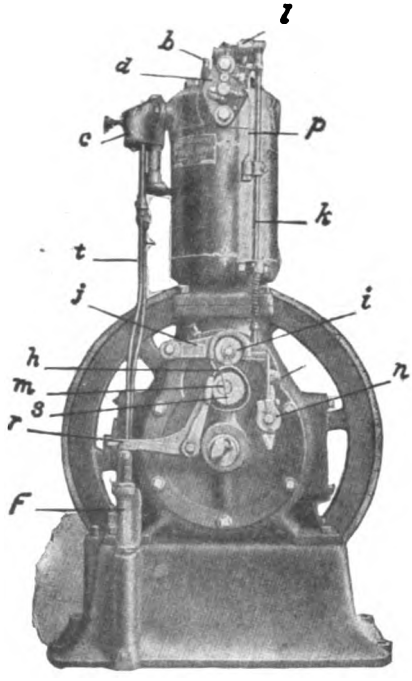


Fig. 5

marine work. In what follows only the four cycle engine will be considered.

Now, however much the four cycle engines now manufactured may differ in design and construction, they are very much alike in the sense

that all of them must perform the same series of four operations, and each operation, though distinct and separate from the others, must be performed in its exact consecutive order and time, or the best results will not be attained.

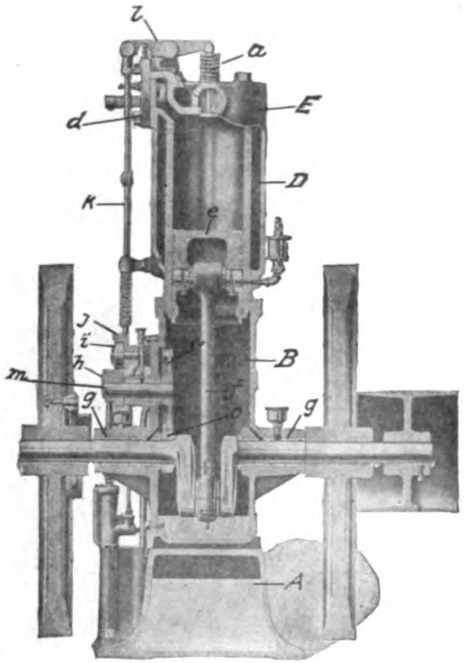


Fig. 6

Fig. 4 shows the governor side of a vertical gasoline engine, Fig. 5 shows the same side with the fly wheel removed, and Fig. 6 shows a sectional view. Fig. 7 shows the top of the cylinder, showing the igniter mechanism enlarged. Fig. 8

shows the governor wheel with the governor weight attached. Fig. 9 is a sectional view of the gasoline mixer or carbureter.

Referring to Fig. 6, it will be seen that the

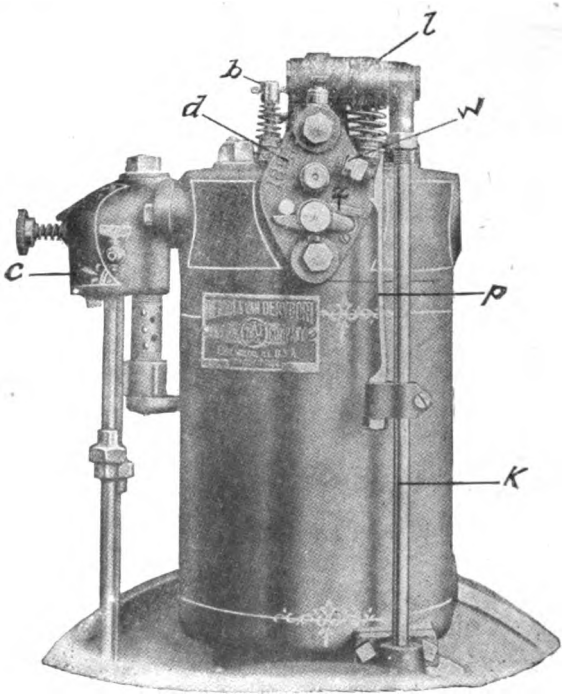


Fig. 7

engine consists of four main castings. The base *A* is cast hollow and forms a reservoir for the fuel supply. The crank case *B* is mounted on this base and is built oil-tight. Access may be

had to the case through the hand hole by removing the cover *C*, Fig. 4. The cylinder *D* is bolted to the top of the crank case, being closed at the top by the cylinder head *E*. The cylinder head contains the exhaust valve *a*, the inlet valve *b*, and to it are bolted the carbureter *c* and the igniter or spark plug *d*. See Fig. 7 also. The cylinder, cylinder head and exhaust valve are thoroughly water jacketed to prevent overheating.

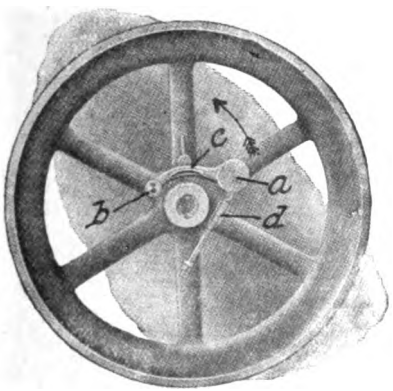


Fig. 8

The piston *e*, it will be noticed, is very long as compared with the piston of a steam engine and is so made for the reason that there are no guides and therefore the piston and cylinder take the thrust of the connecting rod.

The connecting rod *f*, as generally constructed, has a split bushing at the top, or wrist pin end, which can be adjusted to take up the wear.

The crank end is what is known as a "marine end," being finished off in the shape of a T to which the crank pin brasses are held by two bolts.

The crank shaft runs in solid bronze bushings *g*, *g*, which are pressed into the crank case. These bushings have no means of adjustment and are renewed when worn out.

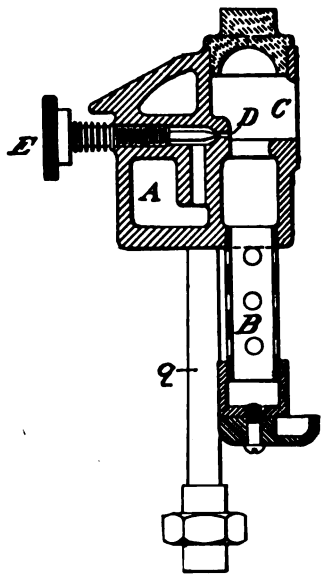


Fig. 9

The exhaust valve *b* is opened by means of the exhaust cam *h*, cam roller *i*, cam lever *j*, valve rod *k*, and exhaust lever *l*. The cam is mounted on the cam shaft *m*, which is rotated half as fast as the main crank shaft by means of

the timing gears *n* and *o*. The exhaust valve is closed by the action of two coil springs, one mounted on the valve spindle and the other on the valve rod.

This engine is governed by holding the exhaust valve open when the speed of the engine exceeds normal. Referring to Fig. 8, as the speed of the engine increases, centrifugal force will move the governor weight *a* outward in the direction of the arrow, it swinging on the pivot *b*. When it has moved out a certain distance, the projecting rib *c* will come in contact with the lower end of lever *n*, Fig. 5, which will throw the upper end of this lever to the left where it will be under the end of the cam lever *j*, thus holding the cam lever up and the exhaust valve open. As the speed of the engine becomes normal, the governor weight will be drawn inward by the action of the governor spring *d*, the rib *c* will not engage with the lower end of lever *n*, and the spring *o* will draw the upper end of the lever to the right, disengaging it from the lever *j*, and thus allowing the exhaust valve to be controlled by the exhaust cam *h*.

The charge in the cylinder is fired or ignited at the proper time by an electric igniter of the make and break type. This igniter is operated by the rod *p*, Fig. 7, attached to the exhaust valve rod *k*, and thus becomes inoperative when the exhaust valve is held open. A more detailed description of the igniter will be given later.

The charge is introduced into the cylinder as follows. Gasoline is drawn from the cavity in

the base and forced to the carbureter or mixer *c*, by means of the pump *F* and pipe *t*. The gasoline is maintained at a constant level in chamber *A* of the carbureter, which is shown in section in Fig. 9, by the overflow pipe *Q*, returning any excess of fuel delivered by the pump to the tank in the base. Air enters the carbureter at *B*, and passes through chamber *C*, to the engine cylinder. As this air passes the opening *D* it takes up a charge of gasoline which has been admitted through the needle valve *E*. The air passes the opening *D* at a velocity of about 6,000 feet per minute and immediately atomizes the gasoline so it forms a gas. When gasoline is converted into a vapor or gas, its volume is increased about 1,500 times. In order that this gas may be burned quickly, or in other words, exploded, it must have sufficient air mixed with it to furnish the oxygen necessary to support the combustion. This will require from 8 to 14 volumes of air for each volume of gas. As an engine will not run satisfactorily unless this mixture is about correct it will be seen that the carbureter or mixer must necessarily be a delicate arrangement. There are several different kinds on the market, the one just described being known as a constant level carbureter.

The fuel pump *F* is of simple construction, having no stuffing box, and the valves being balls. It is operated by the bell crank *r*, and the eccentric *s*, on the cam shaft.

The sectional view Fig. 6 shows the method of lubricating the working parts. Oil is intro-

duced into the crank case through a filling plug. The connecting rod dips into this oil, which by the aid of the dasher attached to the lower end of the rod not only lubricates the crank pin, but the centrifugal force of the crank distributes the oil on the cylinder wall, piston, and sides of the crank case; thus perfectly lubricating the piston, upper end of the connecting rod, timing

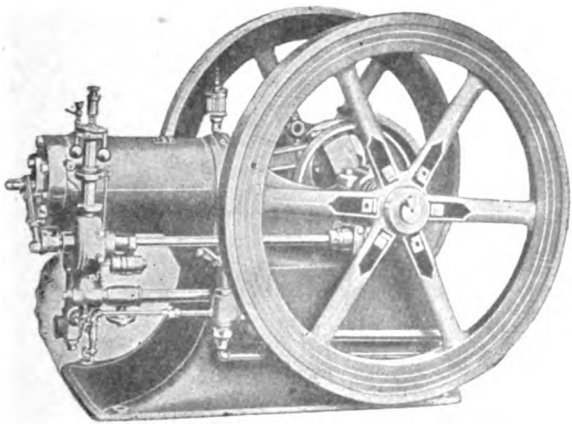


Fig. 10

gears, and by aid of the two oil holes which collect oil from both sides of the crank case, the crank shaft bearings. Grease cups are also provided.

Figs. 10 and 11 show two views of a horizontal gasoline engine in which the governing is done by controlling the mean effective pressure instead of the hit-and-miss plan. This engine takes a charge every second revolution, the

amount of the charge and consequently the force of the explosion being controlled by the governor. While this method of governing is not as economical as the hit-and-miss plan, the speed will be more uniform, hence an engine of this type is suitable for driving machinery where speed variations must be kept within narrow limits. Figs. 12 and 13 show two views

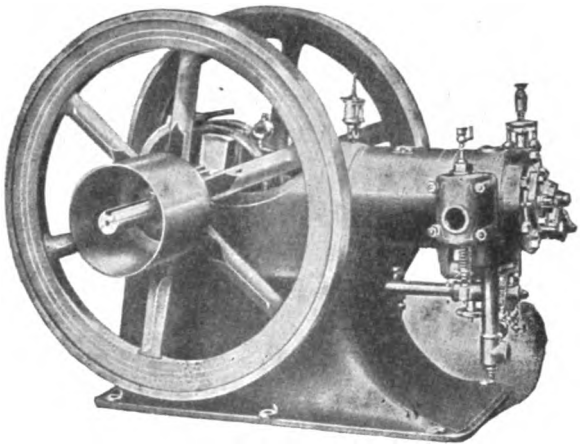


Fig. 11

of the governor mechanism. The cam *a*, which opens the exhaust valve, is fixed on a side shaft *b*, which is driven by spiral gears from the crank shaft. This shaft also carries a cam for operating the pump (not shown), the cam *c*, for operating the igniter, and the bevel gear *d*, for driving the governor. The exhaust valve *e* is operated by the lever *f*, fulcrumed to the bottom of the cylinder. The inlet valve is at *g*, the carbureter

being at *h*. The governor is of the well known fly ball type, provided with a spring adjustment for changing the speed of the engine, and operates as follows: As the speed of the engine increases the governor balls *i*, *i* will move outward, this movement raising the governor sleeve *j*, the lever *k*, and by means of the rod *l* moving a valve on valve stem *m*, located in the intake pipe leading to the inlet valve *g*. This valve partially closes the inlet pipe and thus regulates the amount of the charge taken into the cylinder. As this valve is located between the carbureter and the cylinder, the proportions of the gas and air in the charge are not changed, but as the total quantity of the charge is diminished, the mean effective pressure will be less and the engine will slow down until the governor comes to such a position as will increase the charge.

The igniter is of the same type as that of the engine first described.

Fig. 14 shows a horizontal gasoline engine governed on the hit-and-miss plan, Fig. 15, showing the governor. Referring to these two figures, the exhaust cam *h* is located on a vertical shaft which is driven from the crank shaft by means of the spiral gears *x* and *y*. The upper end of this cam shaft carries a gear *v*, for driving the governor, which is of the same type as that on the second engine described. The exhaust cam moves the slide *a*, and this in turn the exhaust valve rod *k*, also the bell crank *r*, for operating the fuel pump *F*. When the speed of the engine exceeds that for which the gover-

nor is adjusted, the balls move outward, raising the governor sleeve *c*, which in turn moves lever *d*, depressing the detent lever *e*, so that it becomes engaged in the hook up stop *f*, in the slide *a*, thus holding the exhaust valve open.

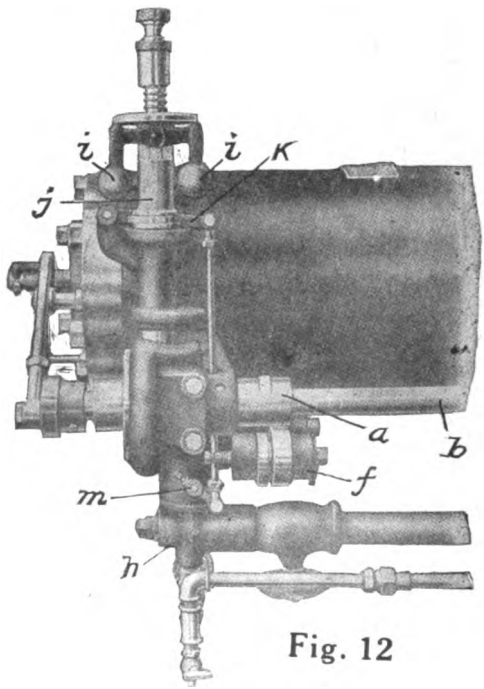


Fig. 12

When the speed of the engine becomes normal the governor balls move inward, raising the detent lever *e*, and the exhaust valve is then controlled by the exhaust cam.

There is another form of governing device of

the hit-and-miss type known as the pendulum or inertia governor. This is shown in Fig. 16 and operates as follows. The exhaust valve rod is in two parts, the part *b*, *b* being connected to the exhaust cam and the part *c* being connected to the exhaust valve. The bracket *d* is bolted to the engine frame and forms a guide for the valve rod, and also supports the detent

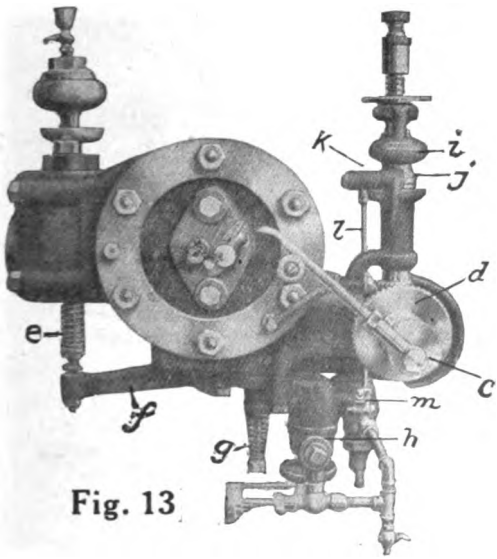


Fig. 13

lever *e*, which is pivoted at *h*. The bracket *a* is clamped to the valve rod *b*, and supports the weight *W*, which is pivoted at *i*, and swings free, except for the resistance of the spring *s*. This weight has a projecting arm *g*, upon which the detent lever *e* rests. On the valve rod *c* is clamped the hook up stop *f*. When the engine is

running at normal speed, the weight *W* will not have throw enough to raise the detent lever *c* high enough to engage with the hook up stop *f*, but as the speed of the engine increases the weight *W* will be thrown far enough to raise the detent lever *e*, so that it will engage with the hook up stop *f*, and thus hold the exhaust valve open.

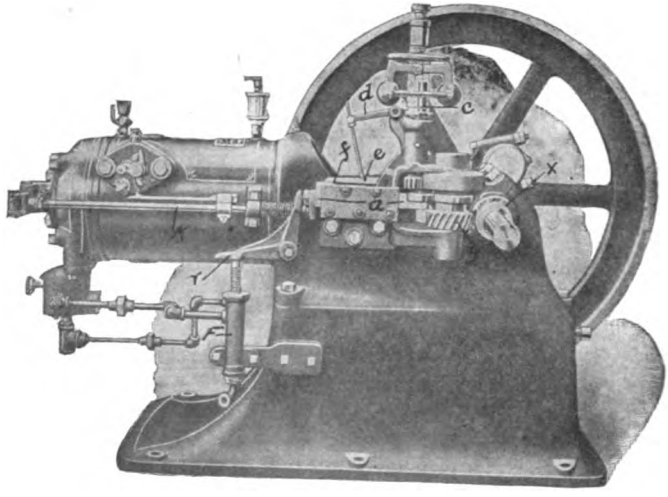


Fig. 14

In the foregoing four typical engines have been described and any four cycle engines governed in the same manner will have some form of apparatus, for performing the functions described, no matter how much these parts may differ from the above in detailed construction. Four cycle engines may be divided into seven

classes, depending on the manner in which the governing is done, as follows:

Hit-and-Miss.
1. Holding gas valve closed.
2. Holding exhaust valve either open or closed.
3. Cutting off current from the igniter.
4. Stopping the action of the cam shaft, generally at a point that will hold the exhaust valve open.

Variable Impulse.
1. Partial stoppage of gas or fuel supply.
2. Throttling the charge, the mixture remaining constant.
3. Varying the lead of ignition.

Referring again to the subject of igniters, there are two general types in use, the hot tube and the electric spark.

The hot tube method of ignition as it is applied to modern engines consists of a small tube varying in length somewhere from 2½ to 6 inches, and about ½ inch in diameter, closed at one end and screwed into the cylinder or cylinder head in such a manner that the open end is in communication with the compression chamber. The tube is heated to a red heat by a burner and on the compression stroke the charge is forced into the tube and against the red hot walls, causing the mixture to ignite. The length and diameter of the tube are such that the mix-

ture is ignited just before the piston reaches the end of the stroke, and the impulse is given the piston as the crank passes over the center. The hot tube seldom fails to ignite the charge, but the time of ignition is not regular and cannot be changed except by changing both the diameter and length of the tube. This method

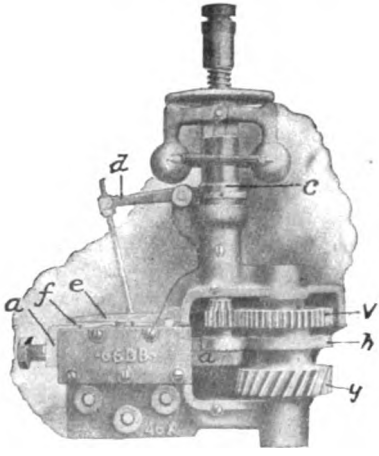


Fig. 15

is not used a great deal at present, having given place to the electric spark.

The electric igniters may be divided into two classes: the one in which the ignition is produced by interrupting a primary circuit flowing through a coil having a great deal of self induction, and the other by interrupting a primary circuit and employing this interruption to induce a current of high tension in a secondary circuit, producing

a spark which will jump across an air space. The first method is known as the make-and-break; the second is called the jump spark. There is little difference in the efficiency of the two systems, although the jump spark method will probably prove more satisfactory for a high speed engine.

The make-and-break method is divided into two classes: the wipe break and the hammer

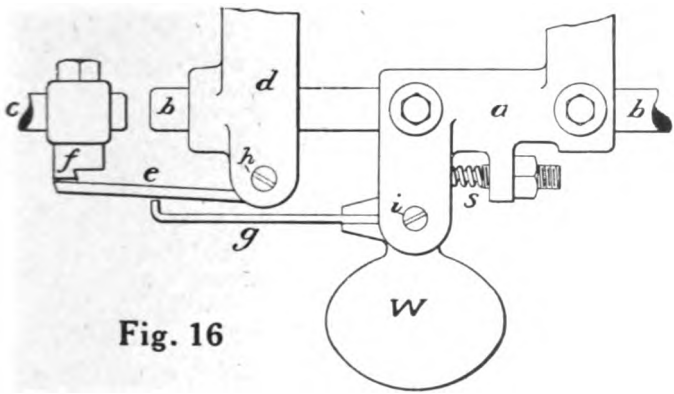


Fig. 16

break. In the first, one terminal is caused to rub upon the other and to suddenly let go, the circuit being closed during the rubbing and a spark will be produced just as the terminals separate. In the second method one of the terminals is forced hard against the other, closing the circuit, and is then suddenly withdrawn by means of a spring, the spark being formed as the terminals separate. As the wipe break is not generally used it will not be discussed.

A hammer break igniter is shown in Fig. 17. The stationary electrode is shown at *a*, and is insulated from the body of the spark plug by the mica and porcelain washers as shown. One

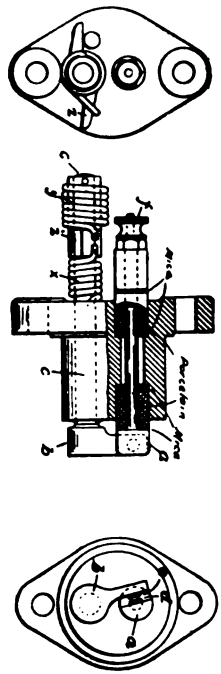


Fig. 17

of the battery wires is attached to this electrode by means of the thumb nut *f*. The movable electrode consists of the arm *b*, on the end of the shaft *c*, *c*. Two small rivets of platinum, *d* and *e*, are inserted in each of the electrodes in

order to avoid the rapid destruction which would occur if the contact were made between the wrought iron surfaces of the electrodes. The shaft *c*, *c* passes through the spark plug, from which it is not insulated, and is free to turn. On the outer end of this shaft the hardened steel piece *z* is placed, being free to rotate about the shaft. The coil spring *x* has one end fast in the spark plug, the other end being fast to the piece *z*. Coil spring *y* has one end fast to piece *z*, and the other end fast to the shaft *c*. Now referring to Fig. 7, attached to the exhaust valve rod is

Fig. 18

the igniter rod *p*, which is a piece of spring steel having the upper end hardened. On the upward movement of the valve rod the piece *p* engages with piece *z*, carrying it upward. This movement of *z* rotates the shaft *c* by means of the coil spring *y* until the electrodes are brought together, after which further movement of the piece *z* winds springs *x* and *y*, increasing the pressure between the points *d* and *e*. As the valve rod continues its upward movement, the beveled end comes in contact with the igniter trip *w*, which disengages rod *p* from piece *z*. Piece *z* flies back, owing to the tension of springs

x and y, and the tension of spring y rotates shaft c and the arm b, breaking the circuit with a rapid motion and producing a spark between d and e.

Fig. 18 shows the form of spark coil used with the hammer-break type of igniter.

Fig. 19 shows the method of connecting the battery and spark coil for a make-and-break igniter.

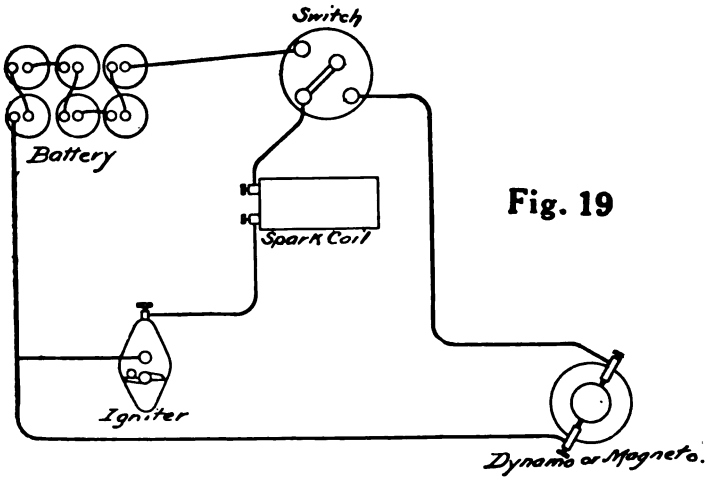


Fig. 19

Fig. 20 shows a spark plug for jump spark ignition. In this construction one electrode a passes through the body of the spark plug b, from which it is thoroughly insulated. The other electrode d is attached directly to the body of the spark plug, making an electrical connection with it. These two electrodes are separated by a small air space e. Fig. 21 shows

the various connections from the battery to the plug, through the induction coil and vibrator. Current from the battery passess through the switch or timer *A*, which is located at any convenient point on the cam shaft. From the battery and switch the current passes through the primary circuit of the induction coil *B*. At *a* and *b* are shown the terminals of the secondary circuit of the induction coil, from which wires are led to the binding posts *c* and *d* of the igniter plug. Attached to the induction coil is

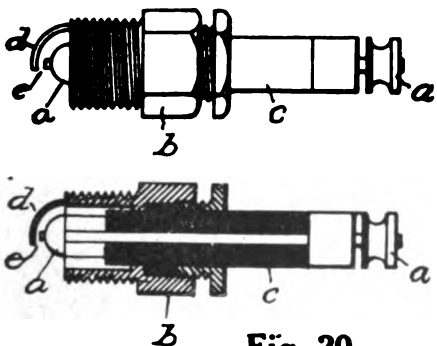


Fig. 20

a circuit breaker or vibrator *e*, which automatically makes and breaks the circuit a great many times a second. In operation the apparatus works as follows: The primary circuit is closed at the proper time by the switch *A* and the current flows to the induction coil. The vibrator rapidly opens and closes the circuit, producing a series of sparks between the points of the igniter plug at *e*. The great trouble with the jump spark method of ignition is due

to two causes: the bridging of the gap *e* by a deposit of carbon, or other foreign material, thus closing the gap and allowing the secondary current to pass without sparking; the other is the breaking down or perforation of the insulation, either in the spark plug or secondary coil of the induction coil, due to the high voltage of the secondary current. To avoid the first trouble care should be used that an excessive amount of lubricating oil is not used in the cylinder, and that what is used is of such quality

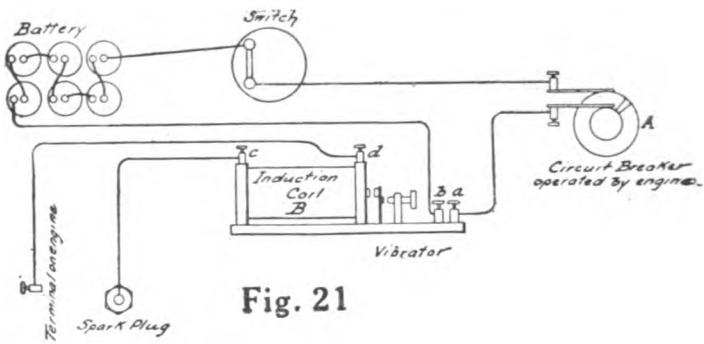


Fig. 21

as will leave the least deposit of carbon. To avoid the second trouble use as low a voltage in the secondary circuit as possible. The best results will be obtained from a fat spark which will jump across a gap of $\frac{3}{8}$ inch to $\frac{1}{2}$ inch, and then so place the igniter points that they will be from $\frac{3}{32}$ inch to $\frac{1}{8}$ inch apart.

Fig. 22 shows an induction coil with vibrator, *a* and *b* being the terminals for the primary circuit, and *c* and *d* being the terminals for the secondary circuit.

Magnetos and dynamos are being used to a considerable extent for ignition purposes in place of batteries and, when properly installed, are giving good satisfaction. Fig. 23 shows a magneto, and Fig. 24 a dynamo. The magneto differs from the dynamo in that the pole pieces are permanent magnets, while those of the dynamo are electric magnets. With the magneto the engine may be started without the use of a battery, but the dynamo will require a battery for starting. As the battery is shut

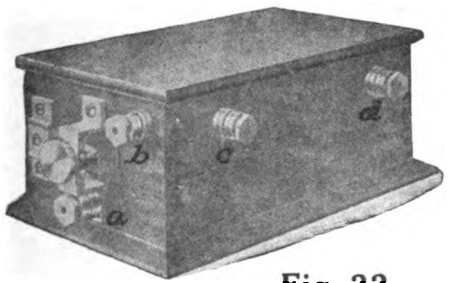


Fig. 22

off immediately after the engine is started, it will last indefinitely. In general, it may be stated that the battery should be used with either as an auxiliary method of ignition.

INTERNAL COMBUSTION ENGINE TROUBLES.

From the foregoing it will be seen that there are three essential conditions which must exist before an internal combustion engine will run satisfactorily.

First. The fuel mixture must be correct.

Second. The compression must be correct.

Third. The charge must be ignited at the proper time.

Mixture.—As previously described, a charge is drawn into the cylinder and there compressed. At the proper moment the charge is ignited and burned, the heat of combustion raising the temperature of the products of combustion to between 2,000 and 3,000 degrees F., and since these gases are confined in the clearance space

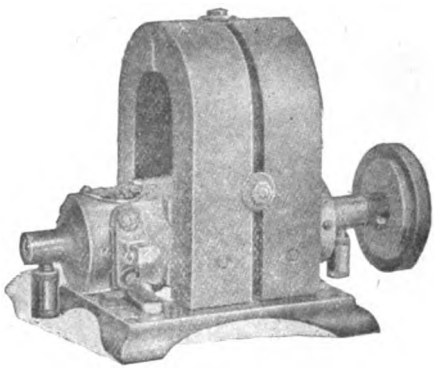


Fig. 23

behind the piston, the expansion due to the heat raises the pressure enormously. Now this resulting pressure depends on the adjustment of the engine and the amount of fuel and air admitted to the cylinder and the proportion in which the two are mixed. In ordinary engines this initial pressure will often amount to between 300 and 400 pounds per square inch. As the piston advances on the power

stroke these gases expand and the pressure falls until at the time the exhaust valve opens it will not be more than 30 or 40 pounds. The principles underlying the combustion of the gas in an internal combustion engine are exactly the same as those governing the combustion of coal in the fire box of a steam boiler. Combustion is a chemical process in which the oxygen

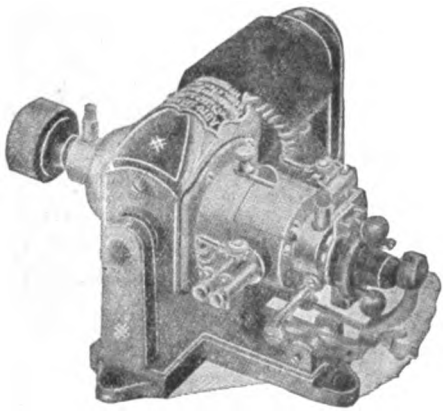


Fig. 24

of the air unites with the carbon and hydrogen of the fuel. Under ordinary conditions, the hydrogen, which is the most combustible of the two elements of which the gas is formed, is the first to burn. The combustion of the hydrogen thus separates it from the carbon, which is then set free; and as carbon is never found in a gaseous condition when uncombined with other substances, it at once assumes the

form of fine soot when the hydrogen is burned away from it. This fine soot, or pulverized carbon, is, however, intensely heated by the combustion of the hydrogen. Now carbon, when heated to an igniting temperature, will, if brought into contact with a sufficient quantity of oxygen, combine with it or be burned. Each particle of carbon thus becomes incandescent, and is immediately consumed by the oxygen which is brought into full activity by the heat, and only a transparent gas is evolved. This process continues as long as there is carbon and oxygen left in the mixture to unite. In case there is too much gas in the mixture in proportion to the amount of air, there will be left a considerable amount of carbon unconsumed on account of the oxygen in the mixture being exhausted. This unconsumed carbon passes away with the exhaust in the form of a dense black smoke, and the power of the engine is reduced.

In case too much air is admitted in proportion to the amount of gas, all of the carbon will be consumed, but the air admitted which is not necessary for the complete combustion of the gas will reduce the resultant temperature of the explosion on account of the heat absorbed by the excess of air and the pressure will be reduced. In this case there will be no smoke from the exhaust, but the power of the engine will be reduced.

From the foregoing it will be seen that the fuel and air must be mixed in exactly the right

proportions to give the best results. If too much fuel is supplied for the amount of air, the mixture will be too rich in fuel and ignition may not take place at all, and if it does, the heat generated will not be as great as would be the case if the proportions were correct. Black smoke thrown from the exhaust shows that the fuel supply is too great.

On the other hand if there is not enough fuel for the amount of air admitted, the mixture will be lean and ignition may fail and the explosion will be weak. This defect is generally made manifest by a snapping or barking noise from the exhaust valve outlet, indicating that the mixture is slow burning and is still burning when the exhaust valve opens. This barking sound has given rise to the saying "She is barking for more fuel," and can be remedied by opening the throttle, allowing more gas to pass to the mixture.

The exhaust has a sound by which the experienced operator soon learns to tell when the engine is or is not doing its work correctly.

If a thick, heavy, *grey* smoke shows from the exhaust it is an indication that the supply of lubricating oil to the cylinder is excessive.

Compression.—It is easy to determine whether or not an engine has compression by turning the piston on the compression stroke. Failure to get compression may be due to a valve refusing to seat, or a leak past a valve. It may also be due to a leak past the piston due to broken rings, poorly fitting rings, or rings gummed up

so they stick. If the valves do not seat correctly, it may be due to dirt or gum under them, or the valve or seat may be worn and require re-grinding. The parts may be out of adjustment due to the wearing of cams, levers, etc., so that the time of opening and closing the inlet and exhaust valves will not be correct. When this is found to be the case the only remedy is a readjustment of the valve gearing. If the inlet valve is controlled by a cam it should open exactly at the beginning of the charging stroke and close exactly at the end. If this valve is operated entirely by suction, the spring should be strong enough to hold the valve in place until the engine has passed the center about 20°, and should remain open during the operation of the suction force, closing on the center. The exhaust valve should be opened when the piston has completed about 90 per cent. of the expansion stroke, and should close exactly at the end of the exhaust stroke. Sometimes the valve stems or springs may bind, thus causing the valves to stick. If the trouble is found to be a leak past the piston, due to the rings being gummed up, the piston should be removed and washed thoroughly with kerosene, working all dirt out from the grooves and making the rings perfectly free. If possible to do so, this cleaning should be done without removing the rings from the piston.

Ignition.—The troubles due to ignition have been generally much magnified, and it may be said that they are due largely to abuse resulting

from ignorance. In another part of this chapter have been given the principles governing the application of electricity for this purpose, and if the following points are thoroughly mastered there should be no trouble experienced in locating any defects in an engine arising from the ignition system.

First. There is a source of electric energy, which may be a battery, auto-sparker, or magneto.

Second. The circuit from this source passes to the electrodes of the igniter either directly or indirectly.

Third. The connections to the spark coil.

Fourth. The automatic arrangement which makes and breaks the circuit.

The battery is by far the most common method of furnishing the electric current, and may be made up of either wet or dry cells. The wet cells will probably give the best results for stationary service, and the dry cells for a portable engine. One of the best types of wet cell is the Edison-Lalande Battery, which is made in several sizes, having a capacity of from 100 to 300 ampere-hours. Five or six of these cells should be used, with the spark coil, for make-and-break ignition. Dry cells will give good results and will prove satisfactory if the run-down cells are replaced by new ones as soon as the current shows weakness. Most of the troubles arising with electric ignition can be traced directly to the battery. Only first-class batteries should be used, and these should not

be expected to last forever without renewing. When dry batteries are used, replace them with new. If wet cells are used, replace any worn out parts and put in a new solution.

High speed engines will use up the battery faster than slow speed, and multiple cylinder engines faster than single cylinder. The size of the engine will make no difference. The actual life of a battery will depend on the duration of the contact, and the hours per day the engine is in use. If the battery is left turned on while the engine is idle, and the engine stands in such a position of the stroke that the contact is made, it will be run down more in a single day than it would be by months of steady use of the engine.

If there is any reason to suppose that a failure to ignite is due to the spark failing to pass on the inside of the cylinder, the wire should be disconnected from the insulated terminal and snapped on some bright part of the engine. If there is a spark it shows that so far as the battery is concerned there is no trouble. If no spark is produced, the wiring should be thoroughly gone over, until the trouble is located and a spark obtained. It will probably be found that a binding screw is loose or the circuit broken in some other manner. If a spark is produced in the above manner, and one is had also when the wire is snapped across the insulated binding post, it shows that there is a connection between the igniter points within the cylinder. In such case the igniter should be removed and cleaned.

If in making this test there is no spark, it indicates that there is no current between the igniter points, and the points should be brought together by means of the igniter dog, and the wire snapped across the insulated binding post. This should produce a spark, and if it does not it indicates that there is something between the points which insulates them, or the points are worn down so that they do not touch. In the first case the igniter should be removed and cleaned. Water and a deposit of carbon will make a circuit between the points, while oil and rust will prevent a contact, and any of these will prevent a spark passing. In case the points are worn they must either be renewed or the igniter adjusted so that they will come together.

With the jump spark method of ignition the trouble, if any, is usually located in the battery, or the wiring, or the spark plug. To locate, proceed about as follows. Turn the engine over until the vibrator buzzes. Open the switch to stop the flow of the primary current and disconnect the wire from the spark plug and hold it about ¼-inch away from some bright part of the engine; then close the switch. If the vibrator buzzes as it should and a good spark is had between the wire and the engine, the trouble is in the plug. Open the switch, remove the plug and connect the wire to it, and lay the plug on the engine so that only the outer casing touches, and again close the switch. If no spark is had between the points of the plug, and a spark is had at any other part of the plug, or if the spark

is intermittent, the plug is short circuited. It should be thoroughly cleaned and the test repeated. If the trouble still exists, the plug insulation is probably perforated, or broken down, and a new plug should be used.

If when the engine is turned over so that the timer closes the circuit the vibrator does not buzz, the wires should be examined to see that none are broken, and that the connections are all tight. If these are found in good order, the timer should be cleaned, as too much oil or dirt will cause it to work poorly. After this is put in good condition and the trouble still exists, examine the vibrator to see that it is not stuck and that the contact points are in good condition. If this is all right, the trouble will be found in the battery being run down. Before throwing any of the cells away each one should be tested with an ammeter to be sure that the trouble is not due to one dead cell.

If a coil without a vibrator is used, the proceeding will be as above, except that instead of turning the engine over, the timer should be operated by hand.

If a magneto or dynamo system is used instead of batteries, the instructions furnished with the outfit should be followed.

From the foregoing it will be seen that to locate ignition troubles it is merely necessary to disconnect certain parts of the circuit and locate the trouble by a process of elimination.

A large portion of the trouble experienced with electric ignition will be done away with if

proper care is used in the installation of the system. All connections must be clean and bright, and *must be tight*. All wires should be run to the engine above the floor, so they will always be in sight and easy to get at in case of trouble. If the engine is in the open the spark plugs should be provided with protectors, or umbrellas, as water is a good conductor of electricity, and the system *must be kept dry*. If a dynamo or magneto is used, the directions for installation furnished by the makers should be followed *exactly*, as each firm placing these goods on the market has a certain way in which they wish their machines to be installed and operated.

The correct point for ignition should vary with the speed of the engine. For about 200 revolutions per minute, ignition should take place when the crank is 10 to 15 degrees from the center approaching it. This angle should increase as the speed increases, and for an engine running about 700 or 800 revolutions per minute the angle would be from 35 to 40 degrees.

With the jump spark the length of time that the timer should hold the circuit closed will depend on the speed of the engine, a slow speed engine requiring a much shorter duration of contact than one running at a high rate of speed.

Repairs.—In making repairs to internal combustion engines the same method of procedure will be followed as would be done in the case of a steam engine of a similar type, bearing in

mind the fact that lost motion which would cause no trouble in the case of a steam engine will often be sufficient to prevent an internal combustion engine from working.

The cylinder should be examined, and if worn out of round, and tapering, as it probably will be, it should be bored, as it is important that the bore be perfectly round, straight and smooth. As the piston and cylinder take the thrust of the connecting rod they wear out of round quite rapidly. The piston should be about $\frac{1}{100}$ inch smaller than the cylinder in small engines, and about $\frac{1}{32}$ inch smaller in large ones, hence when a cylinder is re-bored a new piston should always be fitted. As compression is a vital point, the piston packing rings should fit *perfectly*, both on the inside of the cylinder and in the grooves in the piston. These rings should be turned from 1 per cent to $1\frac{1}{2}$ per cent larger than the cylinder diameter. Thus for a 6-inch cylinder the ring should be from $6\frac{1}{16}$ inches to $6\frac{3}{8}$ inches in diameter. In turning up these rings, the opening should be cut before the outside of the ring is finished to size. The ring should then be clamped in a jig with the ends sprung together, and while in this position the outside should be turned to the exact size of the cylinder. Only in this manner can a tight ring be secured. In springing the ring into the piston grooves, care should be used not to distort it any more than necessary.

All valves should be ground in with emery

and oil to a perfect bearing. The igniter, if of the make-and-break type, should be thoroughly overhauled, and a new movable electrode made and fitted to the plug. This electrode and the plug wear quite rapidly, and all lost motion in these parts should be taken out. The entire valve motion should receive most careful attention, the lost motion being taken out of all pins, rollers, cams, etc.

The crank shaft bearings will probably need truing up and the boxes re-fitted; also, the connecting-rod brasses. As most internal combustion engines are what may be termed "high speed" engines, in that the speed of rotation is high, too much care can not be used in fitting up the bearings. All brasses should butt solidly and fairly together, and the pins should work easily inside of them. The connecting rod brasses should seat squarely on the end of the rod, and the rod end itself must be square, otherwise when the brasses are tightened up the bore will not come fair with the pin and heating will be the result. The brasses should not bear on the fillets. The crank shaft bearings must be lined up exactly at right angles to the cylinder bore.

The water jacket should be thoroughly cleaned out, as some waters will deposit a large amount of scale in a short time. This scale may be loosened by filling the jacket with muriatic acid, removing it as soon as gas bubbles cease to be given off, and thoroughly washing the jacket out with clear water. The acid will not attack

the iron as long as there is lime present for it to work on.

In conclusion, it may be said that in repairing an internal combustion engine, it should be put in as near the condition it was when new as is possible with the facilities at hand.

CHAPTER XIX.

Machine Work—Lathe Work.

The lathe is the oldest of the machine tools and, on account of the great variety of work which it efficiently performs, it is the most important of these tools. In order to adapt it to special conditions the lathe is built in a number of forms, and in some cases the modification is so marked that the relationship to the original type is almost lost. The common form of lathe with which the machinist is most familiar is known as the *engine lathe*, and following it in the order of development are the various types of *turret lathes*, *axle lathes*, *wheel lathes*, *horizontal boring machines*, and finally the *vertical boring mill*, which is simply a chucking or face-plate lathe with the chuck or face plate rotating in a horizontal plane.

In a work of this character it will be impossible to enter into any description of the construction of the various types above mentioned, hence attention will be called to some fundamental principles, the observance of which is necessary in order to produce *good* lathe work. In this connection it is a common thing to hear machinists say that such and such a machine will do *perfect* work. Now we all know that in machine work there is no such a thing as perfection. The best that can be done is to make a piece

of work so that it will come within the limits of variation specified, and if a piece of work will do this it is, to all intents and purposes, perfect. Any time spent on further refinement is time wasted. The best machinist is the man who knows when a piece of work is good enough to satisfactorily perform the work intended.

The errors which occur in lathe work are due to a variety of causes, among which may be mentioned the following.

1. Errors in the construction of the lathe or those due to wear. Also errors in adjustment.
2. Spring of the work.
3. Spring of the tool.

The errors in the construction of the modern lathe are small and for ordinary work will cause no trouble. The errors due to wear of the various parts will be variable, depending largely on the size of the lathe and the character of the work done. The errors due to adjustment will generally be found in the centers not being true and the defective alignment of the tail stock. To produce work turned between centers that shall be correct, the centers must be truly cylindrical, must be turned to exactly the same angle of cone, and the live center must run true, for the following reasons.

As the work is rotated, the work center will wear to fit the dead center. In order to turn a piece of work from end to end, it will be necessary to reverse it in the lathe in order to turn the portion covered by the lathe dog or driver. During the first portion of the cut, one work

center only will have worn to fit the dead center, consequently when the work is reversed, the other work center will wear to fit the dead center and in so doing it will change its position more or less; thus the first turned portion will no longer run true. To overcome this trouble (which is always present) the work should, at the first cut, be turned down to nearly the finished size and then reversed in the lathe and the cut finished. By this time both work centers

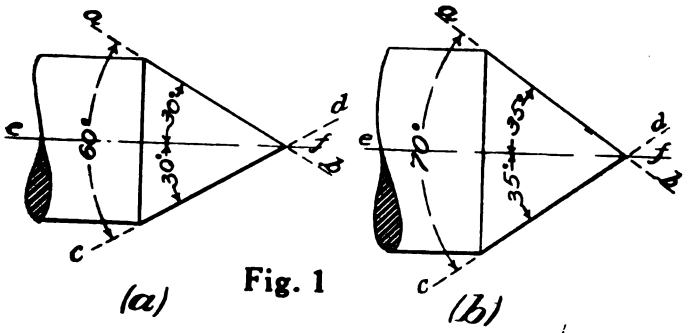


Fig. 1

will have been worn to fit the dead center, and if both centers are exactly the same taper or angle, it is evident that the work centers will fit either lathe center equally well. If the lathe centers are not the same shape it is evident that the work centers will not fit the live center and as a result the work will run more or less out of true at the live center end.

For lathes up to 30 or 36 inch swing, the lathe centers should be turned as shown in Fig. 1 (a). The sides *a*, *b* and *c*, *d* should form an angle of 60° with each other and an angle of 30° with

the center line *e*, *f*. For lathes of larger capacity the centers should be turned to the form shown in Fig. 1 (*b*), where the angle between the sides *a*, *b* and *c*, *d* is 70°, the angle between the sides and the center line *e*, *f* being 35°. If the angle of the centers is made too blunt, the wear of the work center will allow the work to drop out of line more than will be the case if the angle is less, and therefore the adjustment of the centers will have to be attended to closer.

If the live center does not run true the following difficulties will occur. If one end only of the work requires to be turned and it can be finished without changing the driver, the work may be turned straight and truly cylindrical, but the turned portion will not be true with the work center at the live center end. This piece may be removed from the lathe and replaced and it will run true provided the position of the driver is not changed, and also provided that when replaced the tail of the driver enters the same slot in the face plate that it occupied when the turning was done. If the work is reversed in the lathe, the turned portion will run out double the amount that the live center is running out of true. This will be made plain by reference to Fig. 2, where *a* represents the center of rotation, or axis, of the lathe spindle, and the circle *b*, *c*, *d* represents the path of the point of the live center running out of true. If the spindle is true the work will be true with reference to the dead center and the axis *a* of the live spindle, but when the work is reversed it will rotate

on the work center at the dead center end, instead of point *a*, hence will run eccentric. The same thing will be true of the portion turned at the dead center end; hence it will be seen that to produce true work it is absolutely necessary that the live center runs true.

The best way to keep lathe centers true is by grinding them in position in the lathe spindle, and most modern shops will have some form of a center grinding machine. If both centers are to be trued up, the dead center should be trued

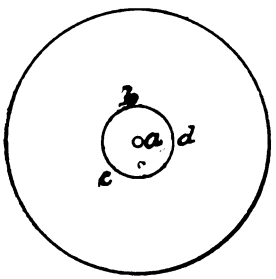


Fig. 2

first, placing it in the lathe spindle in place of the live center. Before placing the center in position for grinding care should be taken that the center and the hole in the spindle are *perfectly* clean, for if there is any dirt present it will throw the center out of line. If the center is trued under these circumstances it would run true until the dirt was removed or the position of the center changed in the spindle, after which it would be untrue at once. The dead center should be polished with fine emery cloth and oil.

In the absence of a center grinder, the centers may be turned true with a tool and finished with a water cut so as to leave a bright and true surface. They should not be finished by filing if true work is to be expected. The dead center should be hardened and have the temper drawn to a straw color. If no great amount of taper turning is done by setting over the tail stock the live center may be left soft. If taper turning is done, the live center should be hardened and

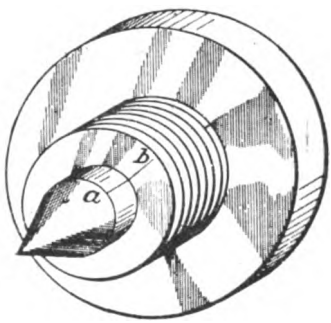


Fig. 3

have the temper drawn to a blue color, which will leave it soft enough to turn. Live centers should not be removed from the lathe spindle unless absolutely necessary, as it is often the case that the hole for the center in the spindle is not absolutely true, and in such cases, while the center will run true in one position, it will not run true if the center is placed in the spindle in a different position. In such cases the position of the live center where it runs true

should be located by marking a line *a* along the center of the lathe center and also a radial line *b* on the nose of the lathe spindle as shown in Fig. 3. The truth of the live center may be tested approximately by moving the tail stock close to the live center and running the lathe at its highest speed so that the eye can determine whether the live center runs true and also whether the dead center is in line with the live center. A more correct test will, however, be had by using some form of a center indicator. These are made in a variety of forms, and a cheap

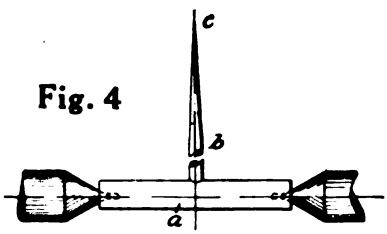


Fig. 4

one that any machinist can make is shown in Fig. 4. It consists of the piece *a*, of any convenient length, having well formed centers in the ends. The pointer *b* is placed in the center of piece *a*, and should be as long as convenient. If placed between the lathe centers as shown, any untruth of the live center will be shown by the movement of the end *c* of the piece *b*. The longer the pointer *b* is as compared with the length of the piece *a*, the more the error of the live center will be magnified. Several tests should be made, rotating the lathe center about a quarter of a turn in the spindle for each test

so as to prove that the center will run true in any position. If it will not do this, the position in which it does run true should be marked as before described. If work as true as possible is desired the live center should always be trued up after it has been removed from the spindle.

In order to produce work which shall be parallel in its length it is necessary that the line joining the live and dead centers, or the axis of the work, shall be parallel to the longitudinal

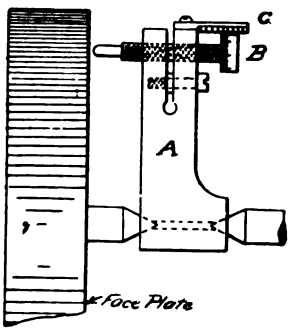


Fig. 5

movement of the tool carriage. If the tail stock is out of alignment the work will be turned larger or smaller in diameter at the dead center end, depending on whether the tail stock is moved toward the back of the lathe or toward the front. The quickest way to test this alignment is with a tool shown in Fig. 5. This tool is especially valuable where one is operating a lathe without a taper attachment, and has to set over the tail stock frequently. The body of the tool *A* is

drilled and countersunk on opposite sides of one end to fit the lathe centers, and on the other end there is the screw *B*, having the head graduated as shown. Just above the head is attached the graduated scale *C*. To use, put the tool between the centers as shown in the figure, clamp the tail stock and turn the tool until it lies in a horizontal position. Turn the screw in until its point touches the face plate. Note the reading of the screw, move it back two or three turns, and indicate by a chalk mark the point where the screw touched the face plate. Turn the face plate half a revolution, also the tool, and take a second measurement. The difference

Fig. 6

between this and the first measurement will give an indication of the amount the centers are out of alignment. If the centers are in line the two measurements will be equal.

A more accurate method, but one which takes more time, is shown in Fig. 6. Place a bar of any convenient length (the longer the better), having two collars *a* and *b*, near each end, between the centers, and take a light cut over each of the collars without moving the cross feed screw. Carefully caliper the size of the collars, and if they are the same size the centers are in line. If not the same size, the tail stock must be adjusted one way or the other,

and the operation repeated until both collars are turned to exactly the same size. Two or three trials should be sufficient.

The error in lathe work caused by the springing or bending of the work is variable and will depend largely, not only on the size of the work, but also on its length as compared with its diameter. A short piece having a comparatively large diameter will spring less than a long one having the same diameter, and where the work is sufficiently long or slender as to cause it to

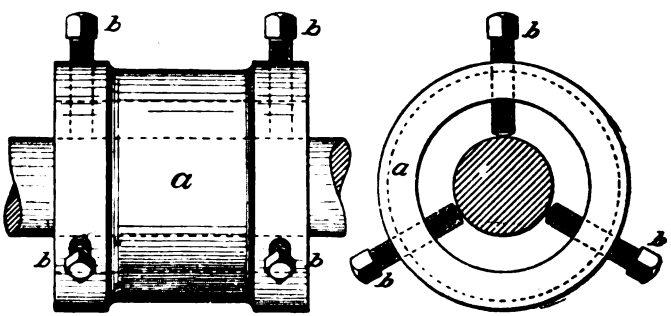


Fig. 7

bend from its own weight, or bend from the pressure of the cut, it must be supported by some form of a steady rest.

The force required to sever the shaving and turn it away from the work acts against the top face of the tool, tending to spring it down, and also reacts in an opposite direction, tending to force or bend the work up. It is evident that as the tool is started from the end where the work is well supported by the lathe center

the spring of the work will be less than it will be when the tool reaches the center of the work. This increase in the spring of the work will cause the tool to take a lighter cut and consequently the work will be turned to a larger diameter. As the tool leaves the center and approaches the live center, the work will spring less and the tool will take a deeper cut. From this it will be seen that the tendency of this spring of the work is to cause it to be turned larger at the center than at the ends. Where this spring is enough to make this difference in size objectionable, some form of a steady rest or follower rest must be used.

In using a steady rest, if the piece of work is to be turned all over, a short portion, situated somewhat closer to the live center than the center of the work, is turned true and the steady rest adjusted to this turned part. This adjustment must be carefully made or the shaft will be sprung out of line, in which case it will not be turned parallel and will not run true when the steady rest is removed. By placing the steady rest to one side of the center of the work at least one-half may be turned before the piece is reversed in the lathe. If the piece does not require turning the full length, the steady rest should be applied as close to the end of the turned portion as possible.

For rough work that is so slender that it is impossible to turn a portion true enough for the steady rest, a sleeve or "cat head," shown in Fig. 7, is employed. This consists of the body

a, which is turned true and has three or four set screws in each end. The set screws are so adjusted to the work that the outside of the body *a* runs true from end to end, and the steady rest is adjusted to the body. If the work is to be turned all over, the "cat head" should be placed closer to the live center than the dead center, and, after turning one-half of the work, it is reversed, the "cat head" removed and the steady rest adjusted to the turned portion. The follower rest is similar to the steady

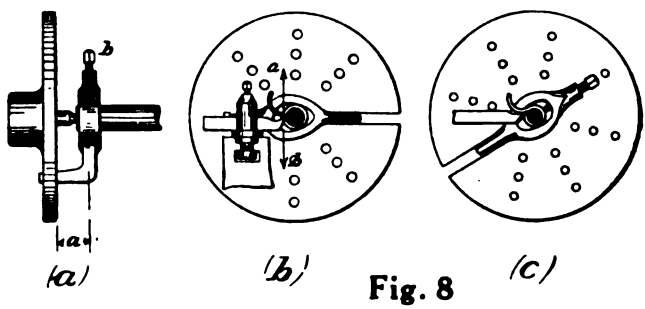


Fig. 8

rest except that it is fastened to the tool carriage and travels with the tool. To use it a short part is turned on the work close to the dead center and the rest adjusted to the turned part.

The method of driving the work sometimes produces strains tending to spring the work more or less, depending on circumstances.

Fig. 8 (*a*) shows the common bent tail lathe dog in position to drive a piece of work. The work is secured in the dog by the set screw *b*.

The tail of the dog is bent around to enable it to pass into the slot in the face plate. This is a very convenient driver and is probably used to a greater extent than any other type, but by its shape two strains are set up, both of which tend to spring the work.

The first of these strains is caused by the leverage exerted by the tail of the driver, and its force depends on the distance *a* which the live center extends out from the face plate. The live center acts as a fulcrum from which the work is bent by the strain caused by the

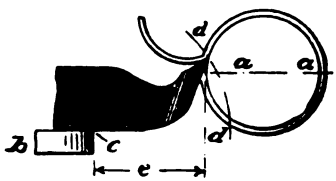


Fig. 9

cut. The second strain is caused by driving the dog from one end only, and is shown in Figs. 8 (*b*) and 8 (*c*). In Fig. 8 (*b*) the tool is shown at the front of the machine and the tail of the driver is at the back. The strain of the cut exerted by the tool tends to bend the work upward as shown by the arrow *a*, while the strain exerted by the driver tends to bend the work downward as shown by the arrow *b*. When the lathe has made one-half of a revolution the tail of the dog will be on the same side of the work as the tool, as shown in Fig. 8 (*c*).

Here the strain of the tool is exerted to spring the work upward and the strain of the dog is also exerted in the same direction. In the first case it is the difference between the two forces which tends to spring the work and in the second case it is the sum of the two forces. It will be readily seen that if the strain of the cut is constant, the resultant force tending to spring the work will vary constantly throughout each revolution and will also change as the tool moves along the work towards the live center. Hence work driven in this manner is

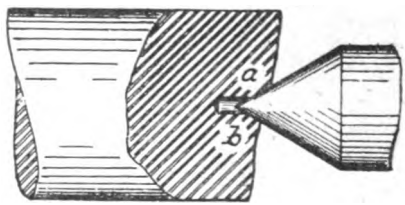


Fig. 10

liable to be turned untrue, or "out of round" as it is commonly called.

The above defects are overcome by using various forms of equalizing drivers and double tailed dogs. If the latter are used, care must be used to see that the two driving pins have an equal degree of contact with the driver, or the advantages of this method of driving will not be secured.

The errors in lathe work caused by the spring of the tool are generally governed by the position of the tool with reference to the center of

the work, the variation in the depth of the cut and the shape and size of the tool.

Referring to the first, the height of the tool with reference to the work is a very important point. Referring to Fig. 9, the line *a*, *a* represents the horizontal center line of the work; *b* represents the tool block, and the point *c* will be the point of support of the tool, and therefore the fulcrum or point from which the tool will bend. It is evident that if the tool springs under the pressure of the cut, its motion will be in the arc of a circle *d*, *d*, having the point *c* for a center, and will spring into the work an amount depending on the distance the point of the tool is set above the center line of the work *a*, *a*, and also on the horizontal distance *e* which the point of the tool extends beyond the point of support.

Referring to the second condition, the amount the tool will spring under given conditions of support and height will vary with every change in the depth of the cut or the hardness of the metal; also, as the tool becomes dull the spring will increase on account of the increased force necessary to force it to its cut.

In view of the above facts, it is evident that to produce work that shall be most true the point of the tool should be set level with the center line of the work. There are, however, three advantages derived from setting the tool above the center line, as follows: first, it severs the metal easier; second, the tool may be given more bottom rake without increasing the clear-

ance; third, the pressure of the cut will act to produce a pressure against the cross feed screw which will keep any lost motion in the parts taken up. For roughing cuts the tool should be of such shape that it may be set above the center of the work, while for finishing cuts where the greatest possible truth of the finished work is desired, the tool should be set on a line with the center of the work.

In general, the errors due to the spring of the tool may be reduced to a minimum by using tools with heavy shanks, clamping them in the tool block with as little overhang as possible, and keeping all joints in the tool slide and carriage tight.

Another source of error in work turned between centers is due to poorly formed work centers. Every good machinist knows that in order to produce true work, the piece operated on must have square ends, and these ends must have correctly formed centers in them. The practice of forming the work centers by simply prick punching them, while a very common practice, should not be tolerated except for the very roughest kind of work.

If an attempt is made to center a piece of work, the end faces of which are not square, the countersinking will not be true with the center hole, and the causes which produce this untruth will also operate to throw the work out of true while it is being turned. Fig. 10 shows a piece of work having an untrue end. As the side *a* is higher than the side *b* the smaller bearing

area at *b* will cause the most wear to occur at that point, therefore the wear of the work on the center will move the countersink over towards *b*. The work centers, should be the same angle as the lathe centers for the reasons given in the remarks relative to correctly formed lathe centers. However, they may be made of a slightly greater angle, say one degree, than the lathe centers, as shown in Fig. 11. In this case the center hole forms a guide for the lathe center and will tend to cause the work center to wear true with the center hole, and

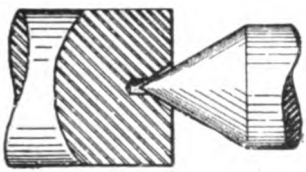


Fig. 11

if this difference of angle is not too great the work center will wear to fit the dead center very rapidly, usually before the first cut is carried over the work. On the other hand, if the work center is reamed, as shown in Fig. 12, it will bear on the lathe center at the mouth and will wear true with the countersinking, and if this countersinking is not true with the center hole, the work is liable to run out when the dead center is fully bedded to the dead center.

The method to be employed for centering work will depend largely on the facilities at hand. For small work a centering machine is

generally provided if there is any great amount of this work to be done. Work which requires to be straightened and tried for straightness in the lathe should be centered temporarily, and not center-drilled until after the straightening has been done. When work is centered by hand, and the center located with a prick punch preparatory to drilling, the center is located by using a center square, hermaphrodite calipers, V-blocks and surface gauge, or "bell center." In this case the drilling and reaming of the centers must be done in the drill press, or lathe, by first drilling a hole from $\frac{1}{16}$ inch to $\frac{3}{32}$ inch

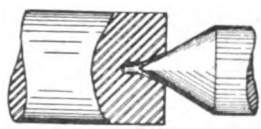


Fig. 12

in diameter, and from $\frac{1}{2}$ inch to 1 inch deep, depending on the size of the work, and the amount to be cut off to bring it to length, and then forming the centers with a center reamer. Work that has very uneven ends should be simply drilled and not reamed until the work ends have been squared up.

The subsequent truth of the work will depend almost entirely upon the care exercised in correctly centering the work and upon the truth of the lathe centers.

Work that has been turned, and from which

the centers have been cut off, may be re-centered as follows: The ends of the work should have small prick-punch centers located as accurately as possible. The dead center is replaced with a "square center," shown in Fig. 13, which has the conical end provided with four flat sides, thus forming four cutting edges. The work is then placed in the lathe with a driver on it, and the butt end of a tool is fed in against the revolving work until it runs true (see Fig. 14). The square center is then fed up slowly and into the work, using plenty of oil. If the work runs

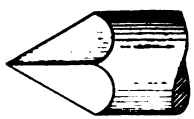


Fig. 13

out, the tool should be fed in again, but be careful not to feed it too far. As long as the square center is altering the position of the center in the work, it will feed forward by jerks, and as soon as it seems to feed steadily, the tool should be withdrawn and the work observed to see that it is running true. The square center should be a few degrees more acute in taper than the dead center, in order that the point of the dead center will not bed at the bottom of the work center. The work should be tried for truth with the dead center in place, as the square center is apt to enlarge the work

center and the work will not run steadily. Care should also be taken not to cut the work centers too large. This may be avoided by feeding the tool up rapidly to the work until it runs true, and feed the square center in only enough to hold the work steady. The end of the tool should be ground smooth and be freely lubricated so that it will not score the finished surface of the work.

Plain Cylindrical Turning. In turning plain cylindrical work the following points should be considered.

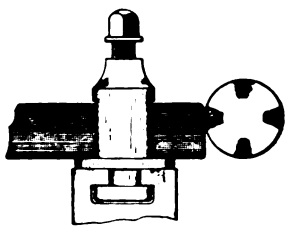


Fig. 14

The work should be cut off to length, making sufficient allowance for squaring up the ends. The amount of this allowance will depend on the method used in cutting off the stock. If a cutting off machine is used, $\frac{1}{32}$-inch will probably be sufficient; if a power hack saw is used, the allowance should be about $\frac{1}{16}$-inch if the saw is running reasonably true; if the work is cut off in the blacksmith shop, or if it is a forging, the allowance should be from $\frac{1}{8}$-inch to $\frac{1}{4}$-inch.

After centering the ends should be squared up with a side tool, and the piece made the correct length. If, in doing this, a considerable amount of stock is removed, the piece should be re-centered.

The next step will be to take a roughing cut, starting from the dead center end, which will reduce the work to within about $\frac{1}{32}$-inch of the finished size. This cut should be carried far enough along the work so that the work center at this end will have worn to a good bearing with the lathe center. The work should be removed from the lathe, the carriage traversed back to the tail stock without moving the cross feed screw, the work reversed, and the roughing cut carried across the balance of the piece. The finishing cut may now be taken.

Whenever practicable a piece of work should be roughed out all over before any part is turned to finished size. This for the reason that all metal work changes its form when the surface or skin is removed, on account of the relieving of the fiber strains due to the forging or rolling. In the case of castings these unequal strains are set up by the unequal cooling of the metal in the mould.

Roughing cuts should always be taken with as coarse a feed and deep a cut as possible, as the object is to remove the surplus metal rather than produce a finish. The maximum amount of metal will be removed in a given time by using a deep cut and coarse feed, reducing the cutting speed if necessary. The finishing

cut should also be taken with as coarse a feed as the conditions will admit, for the coarser the feed the less time the tool will be in service and consequently the wear of the cutting edge will be less than it would be if the feed were finer. The coarseness of the feed and consequently the width of the cutting edge of the tool which can be used for taking the finishing cut will depend on the strength of the piece being operated on to resist springing, and also on the stiffness or rigidity of the lathe and tool. On cast iron, the other conditions being equal, the feeds may generally be coarser than for wrought iron and steel, because the cast iron cuts easier and therefore the work and tool will spring less. But as cast iron has a tendency to break out before the cutting edge of the tool, the finishing cut should be very light. Brass work should be finished with a comparatively fine feed and very quick cutting speed.

In finishing wrought iron and steel in the lathe a very high finish is secured by using a *sharp* tool and using a saturated solution of soda on the tool. The soda in the water will prevent the rusting of the work and machine.

In modern shop practice a great deal of the iron and steel work which was formerly finished in the lathe is now finished by grinding. This gives a much better finish than is possible to get in the lathe and furthermore it is quicker and more accurate.

Turning Taper Work.—There are four methods of turning tapered work in general use, as follows:

1. The dead center is set out of line with the live center.

2. The lathe may be provided with a special attachment for controlling the movement of the cross slide, called a taper attachment.

3. The taper may be turned by swiveling the compound rest to the correct angle.

4. A special lathe may be used in which the head and tail stocks are on a separate bed, which may be set at an angle to the ways governing the movement of the tool carriage.

The first method can be used only for turning outside surfaces, or by means of a suitable traveling head boring bar inside tapered holes may be bored. The last three methods are equally suitable for outside or inside work.

The amount of taper is expressed in several different ways, the most common one being to give the difference in the *diameters* which the two ends of a given taper would have if the taper were one foot long. Thus if a taper is marked as being $\frac{3}{4}$-inch taper per foot, it means that the difference in the diameters of a tapered piece one foot long would be $\frac{3}{4}$-inch. It may also be expressed as the difference in the radii. In the case of keys, wedges, etc., the expression generally means the difference in height in inches of the two ends of a piece one foot long. Sometimes it is expressed as a ratio, as "taper 1 in 16," "2 in 17," etc. Sometimes the included angle is given as a taper of 60 degrees, which would mean that the angle included between the inclined sides will measure 60

degrees. Owing to the above different methods of expressing the degree of taper, unless you are absolutely sure as to just what is intended the only safe way is to ask someone who does know.

While the first method of turning tapers is used to a greater extent in general machine shop work than any of the others, it has several disadvantages, among which are the following:

As the axis of the work is thrown at an angle to the lathe centers, the work centers wear quite rapidly, and generally out of true for the following reasons:

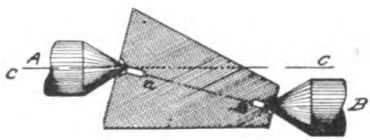


Fig. 15

In Fig. 15 is shown a piece of tapered work supported on the lathe centers. *A* is the live center and *B* the dead center. The line *C*, *C* is the axis of the live spindle, and is parallel to the ways guiding the tool carriage. The line *a*, *b* is the axis of the work. It will be noticed that each lathe center touches the work centers at two points only. Since the work rotates on the dead center the tendency is to wear away the inside and outside edges of the work center, making it a bell-shaped form. At the live center end there is a reciprocating movement

between the centers which tends to wear the work center in the same manner, but in a lesser degree. This wear of the centers makes it difficult to turn a true taper, and if a portion of the work is parallel it will be impossible to get the tapered part to run true with the parallel portion.

The amount which it will be necessary to set over the tail stock to turn a given taper may be arrived at in various ways.

First, it may be calculated. Suppose it is desired to turn up the piston rod as shown in

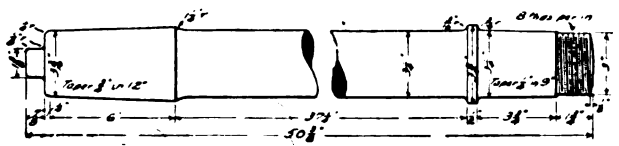


Fig. 16

Fig. 16. The length of the rod is $50\frac{3}{8}$ inches, the taper of the piston end is given as $\frac{1}{4}$ inch in 9 inches, and the taper of the cross-head end is given as $\frac{3}{4}$ inch in 12 inches. Dividing $\frac{1}{4}$ inch by 9 inches gives $\frac{1}{36}$ inch, the taper in one inch. Assuming that the lathe centers will enter each end of the work $\frac{3}{16}$ inch, we can figure on 50 inches as being the distance the lathe centers will be apart. Multiplying $\frac{1}{36}$ inch by 50 inches gives us $\frac{25}{18}$ inch, the total taper in a piece 50 inches long. The tail stock will have to be off-set one-half of this, or $\frac{25}{36}$ inch, which is equal to $\frac{11}{16}$ inch nearly. For the cross-head

end the taper is $\frac{3}{4}$ inch in 12 inches. Dividing $\frac{3}{4}$ inch by 12 inches gives $\frac{3}{48}$ inch, the taper in a piece one inch long. Multiplying $\frac{3}{48}$ inch by 50 inches gives $\frac{150}{48}$ inches, the total taper in a piece 50 inches long. The tail stock must be set over one-half of this, or $1\frac{9}{16}$ inches. As it is impossible to get the exact distance the lathe centers will enter the work, this setting will only be approximately correct and further adjustment will be necessary after the tapered portion is tried into its seat.

Another method of determining the amount to set over the tail stock is as follows:

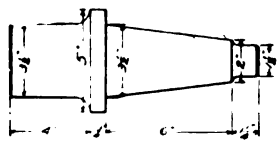


Fig. 17

The taper of the piston end is $\frac{1}{4}$ inch in 9 inches, and instead of figuring the total taper in a piece 50 inches long, we may set the tool at a point 18 inches from the *live* center and adjust the point of the tool $\frac{1}{4}$ inch from the work. Then set over the tail stock until the work just touches the tool. For the crosshead end the tool would be set 2 feet from the live center, and adjusted $\frac{3}{4}$ inch from the work, and the tail stock set over as before. This setting will be correct, no matter what the length of the piece may be.

In case the taper per foot, or per inch, etc., is not given the setting would be arrived at in the following manner: Suppose a piece is to be fitted to a hole which is $\frac{5}{16}$-inch taper in $3\frac{7}{8}$ inches. Multiply the amount of the taper and the length of the taper by some convenient number, say 5: $\frac{5}{16} \times 5 = 1\frac{9}{16}''$, and $3\frac{7}{8} \times 5 = 19\frac{3}{8}''$. Set the tool $19\frac{3}{8}$ inches from the live center, and adjust it to one-half of $1\frac{9}{16}$ inches, or $\frac{25}{32}$ inch from the work. Set the tail stock over until the work just touches the tool.

When the taper per foot or per inch is not

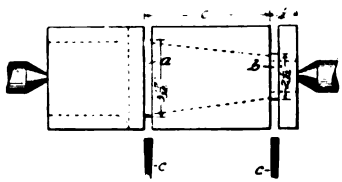


Fig. 18

given, but the two diameters are given with the distance between them, as shown in Fig. 17, a different method is necessary. We may take a cutting-off tool and cut notches in the work at *a* and *b*, as shown in Fig. 18, to within about $\frac{1}{32}$ inch of the required sizes at the ends of the taper, and then adjust the lathe so that the bottom of the notches will measure the same distance from the tool *c*. Various methods are used for making this measurement, and as good a one as any is to use a thin wedge with a line scribed across it, setting the lathe so that

the scribed line will come fair with the top of the tool in each position. A very convenient tool for this purpose is shown in Fig. 19, which consists of a shank *A* with a pivoted pointer *B*, which can be moved like a caliper leg. This tool is clamped in the tool post and is adjusted so that the pivot is the same height as the lathe centers. It is then moved opposite one of the notches and the cross slide adjusted until the pointer will just touch the work. The tool is then moved opposite the other notch, the pointer being turned out of the way, and if the

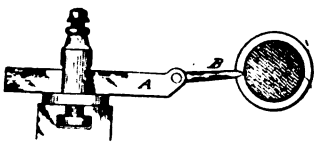


Fig. 19

tail stock is adjusted correctly, the pointer will touch the work with the same degree of pressure that it did in the first instance.

Another method, which is very similar to the foregoing, consists of turning to two diameters, as shown in Fig. 20, the work being turned to the smallest diameter of the tapered part up to its beginning, and to the diameter of the largest portion of the taper up to the end of the taper. The proper adjustment of the tail stock is made in the manner just described.

It must be understood that all of these settings will be approximately correct only; the final

adjustment must be made by trying the piece into the socket in which it is to fit.

As before stated, in turning tapers with the tail stock set over, the wear of the centers will throw the work more or less out of true, and the question arises, in turning up a piece of work having tapered and parallel portions, which part shall be finished first in order that the maximum degree of truth be obtained?

It will be found in practice that the work will be more true if the tapered portion is turned last, as the work centers will alter less when

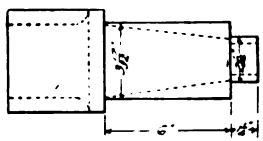


Fig. 20

changed from parallel to taper turning than when changed from the latter to the former. However, in cases where there are parts fitting the tapered portion which are required to be turned after fitting together, as in the case of a piston, it will be better to finish the parallel part last and at the same setting turn up the part fastened to the tapered portion. In the case of the piston rod, shown in Fig. 16, the parallel portion should be roughed out first, then the tapers finished and the thread cut on the piston end. The piston head, which has been roughed out in the chuck, is then secured in

position, and the parallel portion of the rod and the piston are finished.

Where the lathe is equipped with a taper turning attachment, the process is much simpler. In all these attachments there is some form of mechanism for moving the cross slide directly from a guide bar which is set at the required angle to the axis of the lathe. This movement of the cross slide is independent of the cross-feed screw, and at the same time the adjustment of the tool is made in the usual manner by the cross-feed screw. The guide bar is generally

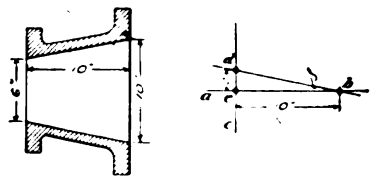


Fig. 21

marked on the end with divisions representing various tapers per foot, but in some cases the divisions represent degrees of angle. The only objection to this form of attachment is the lost motion between the various parts which usually exists, and this must be taken up before the cut starts by starting the cut far enough beyond the end of the work so that by the time the tool has fed up to the work the lost motion will have been taken up.

For boring taper holes in a lathe not equipped with a taper attachment, and for turning and boring steeper tapers than can be done by

off-setting the tail stock, or by using the taper attachment, the compound rest is used. This detail of lathe construction is so familiar that an extended description is unnecessary. Its construction is such that the upper slide which carries the tool may be set and secured in any angular position with the cross slide. The length of cut is limited, but as most steep tapers are short it will seldom be necessary to re-set the tool.

The correct setting of the compound rest is secured in various ways. Generally the base

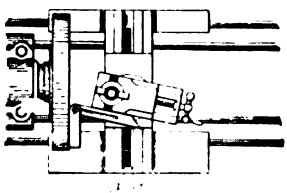


Fig. 22

of the upper slide is graduated in degrees, so that, if the angle of the taper is given, the slide may be set easily. If the degree of taper is not given the setting may be secured as follows: Suppose it is desired to bore the hole in the casting, shown in Fig. 21. Draw two lines *a*, *b* and *c*, *d* at right angles to each other, and from the point of inter-section *e* lay off on line *a*, *b* the distance *e*, *b* equal to 10 inches, the length of the taper. From *e* on the line *c*, *d* lay off the distance *e*, *d* equal to 2 inches, which is half the

difference of the two diameters of the hole. Draw a line through *d* and *b*, and measure the angle *f*, or set a bevel square to lines *c*, *d* and *d*, *b*. The compound rest may then be set to the bevel by using it, as shown in Fig. 22.

The fourth method of turning tapers will not be discussed, as the style of lathe mentioned will seldom be found in railway shops.

In turning tapers it is absolutely necessary that the point of the tool be set at the exact height of

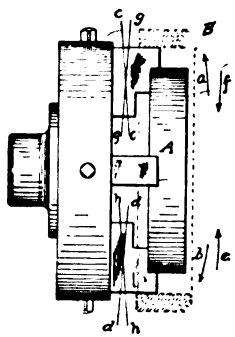


Fig. 23

the lathe centers. This is a point that is often overlooked, and if it is not attended to the taper will have a *curved* outline along its length, and the taper will not be that for which the machine was set. Lack of space will not allow a discussion of why this is so, therefore the reader will have to take the author's word for it. Any variation in setting the tool either above or below the center will result as above, and is

true no matter what method is used in getting the taper. Attention to this detail will save lots of hard filing in order to get the taper to bed properly in its socket.

After a roughing cut has been taken over a taper it should be tried in the piece it is intended to fit. If one end of the taper is too small it will be shown by moving the projecting end in various directions, carefully noting at which end of the taper there is the most movement. The lathe should be adjusted to correct this

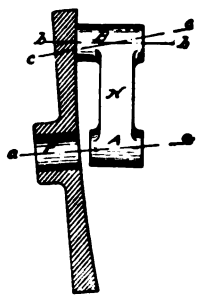


Fig. 24

error and another light cut taken, after which the piece should again be tried in the socket. If no movement is perceptible, three chalk lines should be made along the length of the taper, smoothing the lines with the finger. Then while pressing the taper firmly to place it should be revolved in an opposite direction to that which it had while in the lathe. Upon removing the work the condition of the chalked surfaces will show where the bearing is. Generally,

tapers must fit the holes exactly and go in a certain distance. Thus, in the case of the piston rod, shown in Fig. 16, the taper at the piston end must fit when the shoulder is against the piston. At the other end, the rod must bottom in the cross head when the taper is drawn home. Having fitted a taper as accurately as possible with the lathe tool it should be left slightly large, so that the final fitting may be done by filing or grinding.

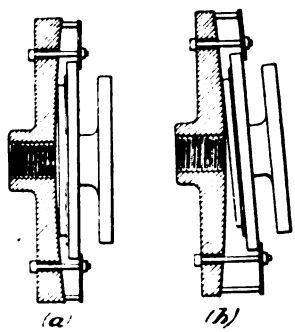


Fig. 25

Chuck and Face Plate Work.—For holding work which cannot be operated on between centers various forms of chucks and face plates are used, and this kind of work, which consists largely of drilling, boring and radial facing operations, is designated as chuck or face plate work.

Lathe chucks are divided into three general classes, depending on how the jaws are operated, as *universal, combination* and *independent* jawed

chucks. As there are a large number of different designs of these chucks in use, no attempt will be made to enter into a detailed description of them other than what follows.

In the universal chuck the construction is such that all the jaws move in and out together. They are made with either two, three or four jaws, and the choice of the number of jaws will depend on the character of the work being handled. Generally the three-jawed chuck is to be preferred, as it is less liable to wear out of

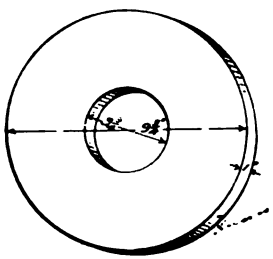


Fig. 26

true, but it has the disadvantage that it cannot be used for square work. These chucks *when new* will center work very accurately, but seldom remain true for any length of time, and their use is limited to milling and grinding machine heads, screw machines, cutting-off machines, etc., where it is desired to quickly center the work.

The combination chuck is so constructed that the jaws may be operated *together* or *independently*. They require considerable care

to keep them in good condition. For some kinds of work this type of chuck proves very satisfactory.

In the independent jawed chuck, as its name indicates, the jaws move independently. This construction enables it to be made stronger than either of the other types, and for general purposes it will prove more satisfactory.

For special work, where the quantity is sufficient to warrant the expense, the form of chuck is made to conform to the special re-

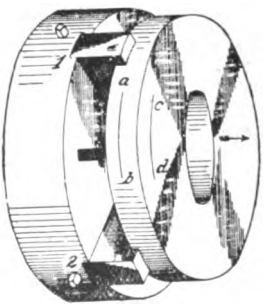


Fig. 27

quirements of the work, hence special chucks are to be found in large numbers.

The lathe face plate is a large circular plate having a series of slots or holes in the face by means of which the work is secured to the plate by bolts and clamps or some form of chucking dogs. Large lathes often have a set of adjustable jaws by means of which the face plate is converted into a very good independent jawed chuck.

The wear of the various parts of a chuck, especially that of the jaws in the slots, tends to throw the work out of true when the jaws are tightened, and sometimes it requires considerable ingenuity on the part of the lathe hand to satisfactorily chuck a piece of work so that it will run true. This class of work requires the most skillful handling, for the reason that in chucked work the relative truth of the various surfaces cannot generally be observed, and the truth of the work will depend almost entirely

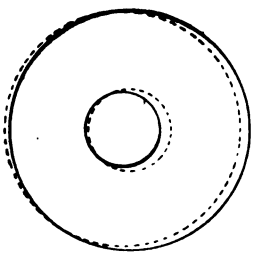


Fig. 28

on the truth of the chucking. Again, the order in which the various surfaces may be most advantageously machined in order to insure the maximum of truth and economy of time demands careful consideration.

The truth of work held in chucks, or secured to face plates, will depend upon the truth of the chucking and the truth of the chuck or face plate.

The errors in the chuck or face plate may be overcome by the proper setting of the work,

but in order to save time and trouble the chuck or face plate should be as true as it is possible to get it. Chucks, especially those of the universal type, should be handled with care, as their value depends upon their ability to hold work true.

Before putting a chuck on the lathe spindle, the threads of both, and the radial faces of the chuck hub and spindle collar, should be carefully cleaned, as the dust on those faces will throw the face of the chuck out of true an amount that will be of considerable importance at the circumference.

The chuck should be held against the nose of the spindle and the thread caught by turning the lathe by hand. If an attempt is made to start the lathe by power and hold the chuck to the spindle, expecting the thread to catch square, it is liable to result in damage to both the chuck and the lathe spindle. Neither should the chuck be allowed to jam hard against the collar, as this will sometimes cause it to stick so hard that difficulty will be experienced in removing it, and the chuck may be damaged. Good chucks are expensive and should be treated with consideration.

As before stated, the principal cause of error in chucks is the wear between the jaws and the slots which gives them play and allows them to cant over. Referring to Fig. 23, which shows a chuck holding a piece of work *A*, any wear between the jaws and the slots will permit the jaws to move in the direction of the arrows *a*

and *b*, the faces of the jaws then standing in the direction of the lines *c* and *d*, instead of being parallel to the face of the chuck. If the wear is equal for each jaw the work would be held true, but as such is seldom the case the face of the jaws form no guide for setting the work true. If the jaws are applied within the work the spring will be in the opposite direction, tending to throw the work out of true in the direction of the lines *e* and *f*.

In the case of face plates, if there is any error in the truth of the surface, it is better to have it hollow than rounding when tested with a straight edge, as in that case a given amount of error in the plate will produce less error in the work, for the following reasons:

Referring to Fig. 24, *F* is a face plate, which is hollow across its face, having the hanger *H* chucked to bore the hole through the hub *A*. The line *a*, *a* represents the center line of the lathe, or line of the tool traverse, and the line *b*, *b* the center line of the hub *B*. As the lines *a*, *a* and *b*, *b* are not parallel it is evident that the holes through the hubs will not be parallel. Suppose that the chuck face was rounding, then the center line of the hub *B* would stand in the direction of the line *c*, *c*, and the holes in the hubs would be bored out of parallel in the opposite direction. In this case the error due to the plate being hollow or rounding would be equal, but opposite in direction.

Referring to Fig. 25 (*a*) and (*b*), which shows a cylinder head held to a face plate by bolts

and clamps. In the first case (*a*) it is evident that the head will be chucked true, notwithstanding that the face of the plate is hollow. If the face of the plate were rounding, as shown at (*b*), the head might be chucked as shown, the surface bearing against the face of the plate not being at a right angle to the center line of the lathe. The truth of the chucking in the second case would depend upon the equal tightening of the clamps upon the work.

The truth of the chucking upon a hollow plate will depend upon whether the work extends equally on both sides of the center line, but in any event the work will be chucked with more truth than can be done if the plate is rounding.

While, by using proper precautions, true work may be produced with untrue chuck plates, it is better to true up the plates so that the face of the work bolted against it will be true and stand at a right angle to the center line of the lathe spindle.

In truing up a face plate, the live spindle bearings should be so adjusted as to take up all lost motion in them, also all end motion should be taken up, and a bar should be placed between the lathe centers to further steady the spindle. The tool should be fed into the work by placing the longitudinal feed nut in gear and operating the feed rod by hand. This will take up all lost motion in the feed gear, after which the carriage should be firmly locked in position.

In securing the work in chucks or to face

plates, care must be taken in tightening the clamping devices, or the work is apt to be sprung more or less. Again, the work will alter in form as the surface metal is removed, and for this reason, especially if the work is light, it is well to loosen the chuck jaws or clamps somewhat before taking the finishing cut.

As a large portion of the chuck and face plate work which was formerly done in lathes is now performed in vertical boring mills, these remarks apply with equal force to both machines.

The methods to be pursued in chucking work may perhaps be best set forth by giving some examples, the first being that of machining the circular plate shown in Fig. 26.

If the hole is cored true a universal chuck may be used, and in case the work does not run true it may be turned around in the chuck and tried in various positions. If it cannot be made to run true by this method, packing pieces may be used between the various jaws and the work. However, if the work is so much out of round as to require this trouble, it will be better to use an independent jawed chuck.

In setting a piece of work in an independent jawed chuck, the jaws should first be set to approximately the size of the work, and also concentric by reference to the circles scribed on the face of the chuck. If the work is heavy it should be supported against the chuck by means of a block of wood placed between the work and the dead center. The jaws are then tightened sufficiently to hold the work, and the

lathe is run at a moderately fast speed. The truth of the work is tested by holding a piece of chalk against the circumference and the radial face. If the work is running true the chalk will touch equally at all points. If not running true the chalk will touch the high side only. Thus, in Fig. 27, if the chalk touches the circumference, as shown by the line *a*, *b*, it would indicate that the two jaws opposite the ones marked 1 and 2 should be loosened, and

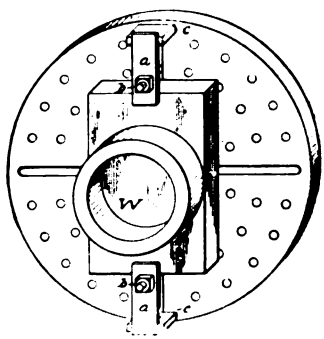


Fig. 29

jaws 1 and 2 tightened, thus moving the work in the direction of the arrow. If the chalk should touch opposite one of the jaws it would indicate that the opposite jaw should be loosened and the one next the mark tightened. If the chalk should touch the radial face, as shown by the line *c*, *d*, it indicates that this portion of the plate should be set in toward the chuck or the opposite side forced out. In this manner all parts of the work should be tested, and the

setting altered until all parts run sufficiently true to enable them to be turned to the required dimensions.

If, as shown in Fig. 28, the cored hole is very much out of center, and this piece is chucked so that the outside runs true, the hole will be so far out of true that it could not be bored out to the finished size. Also, if the cored hole is set true the outside could not be finished to size. In such cases, the piece should be set so that both the outside and the cored hole will run out of true sufficiently to enable them to be finished to size.

In face plate work the work is generally held to the plate by means of clamps and bolts applied somewhat after the manner shown in Fig. 29, where *W* is the work, *a* the plate, *b* the bolts, and *c* the blocks or packing pieces, for supporting the ends of the plates or clamps. With this method of securing work the following precautions are necessary: The height of the packing pieces should be such as will cause the clamps or plates *a*, *a* to stand parallel with the face plates. Suppose the piece is clamped, as shown in Fig. 30, where the piece *c* is too high and the piece *c'* is too low, then in setting the work true it will be found difficult to move it in the direction of the arrow, for the reason that the moving it in that direction acts to force it further under plate *a*, and therefore to tighten it. In the case of plate *b*, the packing piece will be gripped tighter by the plate than the work, and therefore the work will be liable

to move under the pressure of the cut. The plates should also be placed in such a position that they will tend to push the work in driving it rather than pull it. The bolts should be placed as close to the work as possible, because in this position a larger proportion of the bolt pressure will fall upon the work than on the packing piece. Bolts longer than necessary should not be used, as the extra length projecting beyond the surface of the work may prevent

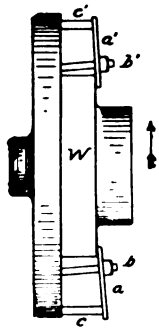


Fig. 30

the slide rest from traversing close up to the work, thus necessitating the tools being extended further from the tool post, which is always objectionable.

In case there is a projection on the work which will prevent the surface that should go against the surface of the face plate from meeting the latter, parallel pieces are used. These are pieces of metal of various widths and thickness,

the corresponding dimensions of the pieces being exactly the same. These pieces are placed between the face-plate and the part of the work which is to be the basis of the chucking. An example of the use of these pieces is shown in the chucking of a rod strap, with the brasses in place, to have the brasses bored and faced, (see Fig. 31).

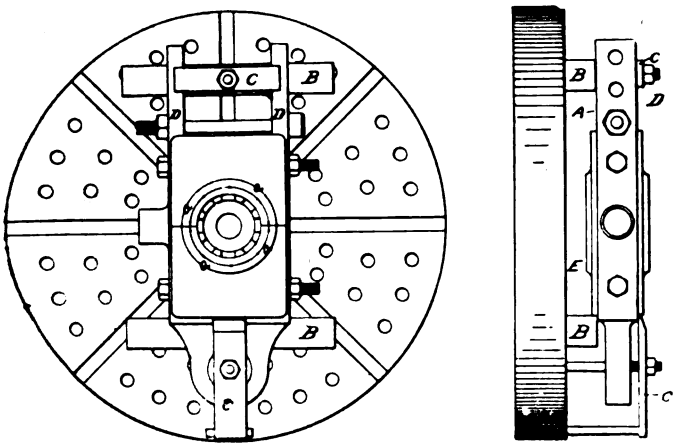


Fig. 31

The object is to chuck the brasses true with the face *A* of the strap, and this is accomplished by using the parallel pieces *B*, *B*. The clamps *C*, *C* must be placed directly over the parallel pieces, otherwise the pressure will bend the work. In some shops it is the practice to plane the outside faces *D* of the straps slightly taper, in which case, if it is desired to have the inside

face of the brass *E* absolutely true, it will be necessary to place sufficient packing between the upper parallel piece and the strap to bring the face *D* of the strap parallel with the face plate. The brass is set to the scribed line *a*, *a*, and should be bored about $\frac{1}{32}$ inch larger than the pin. The side flanges should be faced so that the brass will have from $\frac{1}{64}$ inch to $\frac{1}{32}$ inch lateral motion.

For drilling out solid stock in the lathe, either a twist drill or flat drill may be used. If the twist drill is used some form of a special holder or socket must be used. This socket

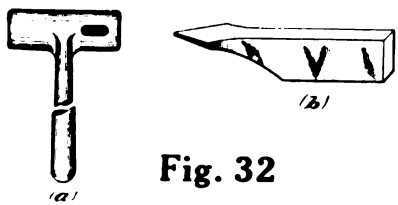


Fig. 32

may fit the tail spindle, or may have a large center in the end to take the dead center. Such a holder is shown in Fig. 32a.

In using any drill, and especially a twist drill, it is necessary that it be started true, and any changes must be made before the outside corners enter the work. For starting a drill true the tool shown in Fig. 32b is used as shown. It is forged with a thin flat point which is ground similar to the point of a flat drill. If such a tool is not available a twist drill may be started true by placing a lathe tool in the tool post and

adjusting it so that the butt end touches the drill. This will steady the point of the drill so that it will generally start true.

The common flat drill is shown in Fig. 33(a), and needs no description. The center in the end *a* should be deep in order to prevent the drill jumping off the center. In using this drill a holder shown in Fig. 33(b) is used. This is a flat piece of iron or steel with one end having a slot cut through to allow the drill to pass

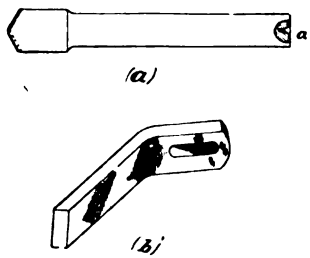


Fig. 33

through, and this end is bent at an angle, as shown.

In using the flat drill to enlarge a cored hole, the holder is clamped in the tool post so that the slot comes opposite the center of the hole. The drill is passed through the slot and fed up to the work by the tail spindle, the holder preventing the drill from turning. If, owing to the cored hole being out of true, the drill shows a tendency to wabble, in order to start it true it will be necessary to place a wrench on the drill,

as shown in Fig. 34. By placing pressure on the wrench, as shown by the arrow, the drill is cramped in the holder, and one side only will cut, thus truing up the hole. The pressure on the wrench is relieved, and the drill fed in further, and it will probably run true; if not, the operation must be repeated.

For further enlarging cored holes, or holes previously drilled through solid stock, the flat

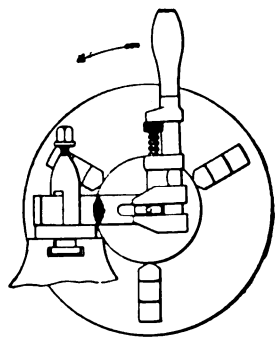


Fig. 34

reamer, shown in Fig. 35, is used in the same manner as the flat drill. These reamers are made from flat steel, and are turned parallel for a short distance to a diameter equal to the diameter of the finished hole. The cutting is performed by the front edges *a* and *b*. If these drills or reamers are carefully made they may be depended upon to produce accurate holes in stock having no blow holes in the bore.

However, for finishing holes to exact size, any

of the various forms of rose, three-fluted or fluted-chucking reamers should be used.

Where holes of odd sizes are to be produced, the boring should be done with a boring tool held in the slide rest. If the holes are of small diameter especial care must be taken that the tool is so ground and set that it will have proper clearance. The first cut should be as heavy as the tool will stand, so as to clean up the hole all around, after which one or more finishing cuts may be taken to bring the hole to exact size. Sometimes a more accurate bore is secured by taking the last cut from the head

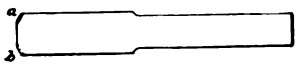


Fig. 35

stock toward the tail stock, as in this case the tool is under tension, and the spring is less.

For boring holes in work that cannot be conveniently secured to the face plate, or where the holes are long, the work is secured to the lathe carriage, and the boring is done by means of a tool held in a bar secured between the lathe centers and rotated by means of a suitable driver. Fig. 36 shows a common form of a boring bar in which the tool *a* is held by means of the wedge *b*. The cutter is generally turned to the desired diameter before hardening, and the cutting is done by the two edges *c* and *d*. The bar must be at least twice as long as the

hole to be bored. The work to be bored is set central with the bar.

For boring large holes various styles of traveling head-boring bars, having a number of tools affixed to the head, are used. In using this style of bar the truth of the hole will depend largely upon the truth of the bar, and the tools should be carefully set so that each one will do its share of the cutting.

Tapers may be bored with a traveling head boring bar by off-setting the tail stock in the same manner as was described for turning tapers.

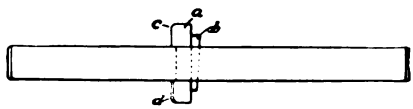


Fig. 36

Cutting Screw Threads in the Lathe.—Screw threads are generally cut in the lathe by means of a suitably formed single-pointed tool held in the slide rest. The slide rest is traversed along the bed by means of a lead screw which is rotated by a system of gearing or change wheels so that the lateral movement of the slide rest for each revolution of the lathe spindle is equal to the pitch of the thread to be cut.

There are four types of screw threads in general use in this country, as follows:

1. The V-Thread.
2. The United States Standard.
3. The Square Thread.

4. The Acme Standard.

Fig. 37 shows a section of the common V-thread. The sides of the thread are straight and make an angle of 60° with each other, and 60° with the center line of the screw. The junction of the threads at the root is sharp as well as the top, hence the name.

Fig. 38 shows a section of the U. S. Standard thread. This thread was derived from the V-thread by dividing the depth of the sharp V-thread into 8 equal divisions, and taking off one of the divisions at the top and filling in another at the bottom, thus making the total

Fig. 37

height of the thread three-fourths that of a V-thread of the same pitch.

Fig. 39 shows the square thread, which is, as the name implies, square in section. In practice, the width of the space *a* is made slightly greater than the thickness *b* of the thread. This thread is suitable for constructions where there is a large amount of wear, and also has the advantage that the pressure does not tend to split the nut, as is the case with the V-thread and the U. S. Standard thread. However, it is difficult to make, and to a large extent has given place to the Acme form of thread.

Fig 40 shows a section of the Acme Standard thread, which was designed to replace the square form, giving the advantages of greater ease in making fits, and provision for take-up in case of wear. The dimensions are the same as those of square thread screws, with the exception that the sides of the thread, instead of being perpendicular to the center line of the screw, are inclined $14\frac{1}{2}°$ to such perpendicular, making the angle included between the two sides of the thread 29°. The depth of the thread = $\frac{1}{2}$ of the pitch; the width of the top of the thread = width of space at the bottom =

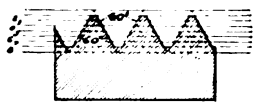


Fig. 38

.3707 × pitch; the thickness at the root of the thread = width of space at the top = .6293 × pitch. This form of thread is much used for lead screws.

The following descriptions refer to the various parts of screw threads:

The *diameter* of a thread is the diameter measured over the points of the thread, or the diameter of the bolt before the thread was cut.

The *root diameter* is the diameter measured over the bottom of the threads.

The *height* of the thread is the vertical distance from the root to the point.

The *pitch* of a thread is the number of turns

it makes in advancing one inch along the screw.

A *right-hand* thread is one which, when being screwed into a nut, turns in the direction of the hands of a clock. The nut when being screwed onto a right hand thread turns in a counter direction. This is the common form of thread.

The *left-hand* thread turns in an opposite direction from that of a right-hand thread.

A *single* thread has one spiral projection which advances along the bolt an amount equal to the pitch.

A *double* thread has two spiral projections which advance twice the apparent pitch each revolution.

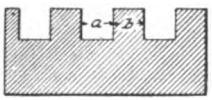


Fig. 39

A *triple* thread has three spiral projections which advance three times the apparent pitch each revolution.

Fig. 41A shows a double thread, and Fig. 41B a triple thread. The object of these multiple threads is to increase the motion without the use of a coarse pitch single thread, which increased depth would weaken the body of the bolt.

For cutting threads in the lathe various forms of slide-rest tools are used. The common forged thread tool for outside work is shown

in Fig. 42. It is ground flat on top, and the side faces *a*, *b* and *c d* are ground so as to form an angle of 60°, this angle being tested with the common thread gauge, shown in Fig. 43. In using this gauge it must be applied to the tool so that it lies flat with the top face of the tool in the line *e*, *f*, Fig. 42. If held in any other manner, while the sides of the tool may be ground to fit the gauge, the thread cut will not be correct.

Figs. 44A, 44B and 44C show the method of using the thread gauge for setting the tool correctly, the first two figures showing the

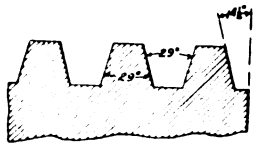


Fig. 40

application to an outside tool, and the last figure the setting of an inside tool.

The tool must be firmly clamped in the tool post and the work driver securely fastened, for any slip of either will probably result in spoiled work. The proper change wheels must be placed in position, and the tool fed up to take a light cut which is carried along the work the desired distance. At this point the tool is quickly withdrawn from the work by means of the cross feed screw, and the motion of the lathe reversed. The tool is allowed to run

back to the starting point, when the lathe is again reversed, and the tool fed in far enough to take another cut. This series of operations is continued until the screw is cut to the required size.

A majority of lathes are provided with a stop, as shown in Fig. 45, to keep the tool from being fed in too deep. It consists of the piece *a*, which is secured to the carriage by the set screw *b*. The screw *c*, having a shoulder and knurled head, passes loosely through the stop and screw into a suitably tapped hole in the

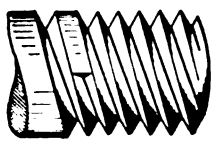


Fig. 41 A

cross slide carriage *d*. When the stop is adjusted the tool may be moved away from the work, as the stop screw slides loosely through the stop, but the tool can be fed in only until the shoulder on the stop screw strikes the stop. After taking a cut over the work, the tool is advanced to take the succeeding cut by unscrewing the stop screw *c* part of a turn. For cutting internal threads the stop screw is not run through the stop, but is placed so that the head will bear against the inside face of the stop, and is screwed into the tool slide to take the successive cuts.

Some lathes are so constructed as not to require the motion of the spindle to be reversed in order to run the tool back to the end of the work for the successive cuts, the reversing of the tool carriage being done from the apron. In cutting long screws time will be saved by stopping the lathe, opening the lead nut and traversing the carriage back by hand a certain definite distance, depending on the pitch of the thread being cut. Thus, if the threads being cut are any *whole* number per inch, the lead nut will properly engage with the lead

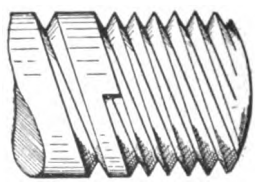


Fig. 41. B

screw, if the carriage is moved back from the stop position any number of *inches*. If the number of threads per inch is an *even* number, the carriage may be moved back any number of *half inches*. If the thread is fractional, the carriage must be moved back a number of inches which will contain an *even number of threads*. Thus, if an $11\frac{1}{2}$-pitch thread is being cut the carriage may be stopped every two inches. If a $2\frac{1}{4}$-pitch thread, the carriage may be stopped every four inches. With a little practice the above method of handling the

carriage may be done very rapidly. When the pitch of the thread to be cut is a multiple of the pitch of the lead screw, the nut may be opened and closed at any point.

As before stated, in order to cut threads of different pitches with the same lead screw, the lathe must be provided with a set of change gears, so that the advance of the tool carriage for each revolution of the spindle will be exactly equal to the pitch of the thread being cut.

These gears are arranged in two ways. When

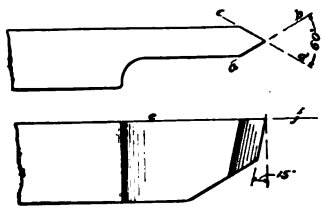


Fig. 42

arranged as shown in Fig. 46, the lathe is said to be single-geared, as the stud *S* makes the same number of revolutions per minute as the lathe spindle. If the gear *A* on the spindle and gear *B* on the stud are not the same size, so that the stud *S* does not make the same number of revolutions per minute as the spindle, the lathe is said to be compound-geared. The first arrangement is the more common. All lathes are, or should be, provided with an index plate showing the proper gears to be used for cutting the different pitches, but in cases

where this plate has been lost, or in case some odd pitched screw is to be cut, the proper gears may be determined by means of the following proportions:

The pitch of the lead screw is to the pitch of the screw to be cut, as the number of teeth in the gear on the spindle is to the number of teeth in the gear on the lead screw.

Placing the above expression in the form of a fraction will give:

$$\frac{\text{Pitch of lead screw}}{\text{Pitch of screw to be cut}} = \frac{\text{No. of teeth in wheel on spindle}}{\text{No. teeth in wheel on lead screw}}$$

The application of the above equation is as follows: Suppose it is desired to cut a thread of 9 pitch in a lathe having a 4-pitch lead screw. Substituting these values in the above will give:

$$\frac{4 = \text{No. of teeth in wheel on spindle.}}{9 = \text{No. of teeth in wheel on lead screw.}}$$

As in practice it is impossible to use gears having much less than 20 teeth, it will be necessary to multiply both the numerator and denominator of the first member of the equation by the same number. Starting with 2, we would get the following:

$$\frac{4\times2}{9\times2} = \frac{8}{18},\ \frac{4\times3}{9\times3} = \frac{12}{27},\ \frac{4\times4}{9\times4} = \frac{16}{36},\ \frac{4\times5}{9\times5} = \frac{20}{45},\ \frac{4\times6}{9\times6} = \frac{24}{54},\ \frac{4\times7}{9\times7} = \frac{28}{63},$$

hence we could use gears having the following number of teeth: 8 and 18, 12 and 27, 16 and 36, 20 and 45, 24 and 54, 28 and 63, and so on. Generally, the number of teeth in gears

of any change set increase in number in a regular manner, as 20, 24, 28, 32, 36, etc. When this is the case, the difference between the number of teeth may be used to multiply both terms of the fraction, as above. If the lathe is equipped for cutting fractional threads, as the 11½-pitch pipe thread, there will be some gears that will not correspond to the regular ratio of the balance of the set.

In the case of fractional threads the above rule holds good, and the compound fraction which will result must be reduced to a simple fraction before proceeding with the multiplication.

Thus, suppose it is desired to cut a pipe thread of 11½ pitch on the above lathe. The fraction would be:

$$\frac{4}{11\frac{1}{2}} = \frac{4}{\frac{23}{2}} = \frac{8}{23},$$

and multiplying as before, we would have

$$\frac{16}{42}, \quad \frac{24}{69}, \quad \frac{32}{92}, \text{ etc.}$$

Hence, we could use gears having the following number of teeth: 16 and 42, 24 and 69, 32 and 92, etc.

In case the lathe has a set of compound gears in the head so that the stud for the change gear does not make the same number of revolu-

tions as the lathe spindle, the *apparent pitch* of the lead screw must be used in the calculations instead of the actual pitch. For example, if the stud for the change gear is connected to the spindle by a train of gears, so that it makes two revolutions for each revolution of the spindle, the apparent pitch of the lead screw will be twice the actual pitch. In the above case, if the lead screw is 4 pitch, the apparent pitch will be 2. In cases where the apparent pitch cannot be easily determined by inspection, the lathe should be geared with equal wheels on the stud and lead screw, and a thread cut

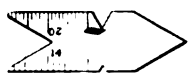


Fig. 43

upon a piece of work. This thread will be the apparent pitch of the lead screw and should be used in all calculations.

Sometimes lathes are arranged to compound the gears as shown in Fig. 47. In this case the intermediate gear is made up of two gears *a* and *b*, keyed together on a sleeve which turns on the intermediate stud. One of the gears *a* is driven by the stud gear, while gear *b* acts as a driver for the lead screw gear.

With this arrangement of gears the following rule will apply:

Write a fraction having the pitch of the lead screw for the numerator and the pitch of the desired screw for the denominator. Factor

both numerator and denominator into two numbers, thus giving two fractions which multiplied together will give the original fraction. Multiply the two resulting fractions by a common number which will give two other fractions, the numerator of the first representing the number of teeth in the gear on the stud and the denominator representing the number of teeth in the driven gear on the intermediate stud. The numerator of the second fraction will represent

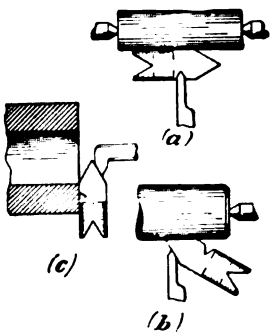


Fig. 44

the number of teeth in the driving gear on the intermediate stud, and the denominator the number of teeth in the gear on the lead screw.

Suppose it is required to cut a screw of 48 pitch in a lathe having a 6-pitch lead screw. Applying the rule given we have $\frac{6}{48} = \frac{2 \times 3}{8 \times 6} = \frac{2}{8} \times \frac{3}{6}$; multiplying the numerator and denominator of both fractions by 10, we obtain $\frac{20}{80} \times \frac{30}{60}$. Therefore a 20-tooth gear on the stud meshing

with an 80-tooth gear on the compound stud, with a 30-tooth gear as the driver on the compound stud meshing with a 60-tooth gear on the lead screw, will cut the desired thread. It makes no difference which fraction is considered first, as a 30-tooth gear on the stud meshing with the 60-tooth intermediate gear, and the 20-tooth intermediate gear meshing with the 80-tooth gear on the lead screw, will produce the same result.

In single-geared lathes and also lathes compounded in the head stock, the size of the intermediate gear is immaterial, any gear being used

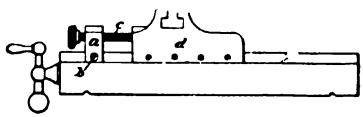


Fig. 45

which will conveniently mesh with the two other gears.

As lathes are usually geared, they will cut a right-hand thread by using one intermediate gear, so that to cut a left-hand thread it is necessary to place a second intermediate gear in the train. The size of this second gear is immaterial. If the lathe has a reverse in the head stock it will not be necessary to use the second intermediate gear.

The tool used for cutting U. S. Standard threads is similar to that used for cutting V threads, except that a small portion is ground

from the point, making it flat. The width of this flat varies for each pitch, hence it is necessary to fit the tool to a properly formed gauge, or a standard tap of the pitch required. In other respects the operation of cutting the thread is identical with that of the V thread. Care must be taken not to cut the thread below size at the root. The following table gives the diameter of the screw, the number of threads

PITCH OF UNITED STATES STANDARD THREADS.

Diam. of Screw. Inches.	Diam. at Root of Thread. Inches.	No. of Threads. Per Inch.	Diam. of Screw. Inches.	Diam. at Root of Thread. Inches.	No. of Threads. Per Inch.
¼	.185	20	2	1.712	4½
5/16	.240	18	2¼	1.962	4½
⅜	.294	16	2½	2.175	4
7/16	.344	14	2¾	2.425	4
½	.400	13	3	2.629	3½
9/16	.454	12	3¼	2.879	3½
⅝	.507	11	3½	3.100	3½
11/16	.620	10	3¾	3.317	3
¾	.731	9	4	3.567	3
1	.837	8	4¼	3.798	2¾
1 ⅛	.940	7	4½	4.028	2¾
1 ¼	1.065	7	4¾	4.255	2¾
1 ⅜	1.160	6	5	4.480	2½
1 ½	1.284	6	5¼	4.730	2½
1 ⅝	1.389	5½	5½	5.053	2½
1 ¾	1.490	5	5¾	5.203	2½
1 ⅞	1.615	5	6	5.423	2¼

per inch, and the diameter at the root of the thread for all sizes from ¼-inch to 6 inches, inclusive.

For cutting square threads a tool similar in shape to an ordinary parting or cutting-off tool is used, except that the angle of side clearance must be great enough to allow the tool to cut. Fig. 48 shows such a tool. The tool is made wider at the cutting edge *a* than at *b*, so that the

cutting will be done by edge *a*, and the sides *c* and *d* clear. The sides of the tool from *e* to *f* must be inclined to the body of the tool as shown. The degree of inclination depending upon the pitch of the thread to be cut and the diameter of the work. This angle may be determined by the construction shown in Fig. 49. Draw the line *a*, *b*, having a length equal to the circumference of the thread to be cut, measured at the root. At *b* erect the perpendicular *b*, *c*, having a length equal to the pitch of the thread, and join *a* and *c* with a straight line. The inclina-

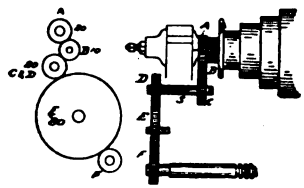


Fig. 46

tion of line *a*, *c* to line *a*, *b* is the angle of the thread at the root, and the angle of the tool sides must be enough greater to give the necessary clearance.

In cutting a square thread, a hole equal in diameter to the width of the thread groove and having a depth equal to the depth of the thread should be drilled at the termination of the thread for the relief of the cutting tool. This enables the thread to end abruptly and makes a neat finish.

For cutting the Acme thread, the tool must be

ground to a properly formed gauge and the sides cleared as for a square thread tool.

In cutting all threads the point of the tool should be set level with the work axis and also square with the same. This also applies to a taper thread cut by setting over the tail stock.

In cutting coarse pitch threads, time may be saved by using a tool formed as shown in Fig. 50, having the cutting edge *a*, *b* ground at an angle of 60° with the side *c*, *d* of the tool, and giving the cutting edge top rake. To use this

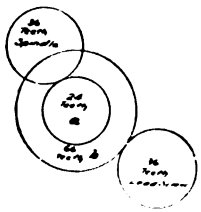


Fig. 47

tool, the compound rest is set at an angle of 60° with the work axis, as shown in Fig. 51, and the cut is put on by operating the feed screw of the compound rest. With this tool a much heavier cut may be taken than with the common form of tool.

When a double thread is to be cut the method is the same as that of cutting a single thread. The first thread is finished to size, then the work is given one-half a turn and the second thread cut. The work may be given the half turn by removing it and replacing it in the lathe with

the tail of the driver in the slot in the face plate directly opposite the one used while cutting the first thread. Another method is to disconnect the feed gears and give the lathe and work half a turn as denoted by the change gears.

In cutting triple threads, after the first thread is cut the work must be rotated one-third of a turn and the second thread cut. Then the work is again rotated one-third of a turn and the third thread cut. Quadruple threads are cut in the same manner, turning the work one-fourth of a turn after each thread is cut.

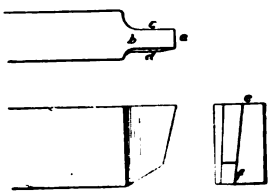


Fig. 48

Cutting Speeds and Feeds.

As the output of a machine, and therefore the cost of the work, depends largely on the cutting speed and rate of feed used, these are matters of great importance.

The *cutting speed* is the speed at which the surface of the work passes the cutting edge of the tool, and is generally expressed in feet per minute. It is the product of the circumference of the work multiplied by the number of revolutions per minute.

The *rate of feed* is the amount of tool traverse per revolution of the work.

The introduction of high speed tool steels has had a remarkable effect upon the output of certain classes of work, especially the turning and boring of tires, and the removing of surplus stock from forgings and castings, when the work is rigid enough to stand the pressure of the increased speed and cut. This class of work is being done from three to five times as fast as was possible with common tool steels.

However, these "high speed" tool steels seem to give no better results for finishing cuts than the common steels, for the reason that the new

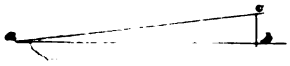


Fig. 49

steels must be very hot in order to give them the maximum hardness; and if an attempt is made to finish work at high speed, chattering will occur despite all precautions, and, in practice, this means rough surfaces.

In the majority of machine operations, the chief item of cost is not that of taking rough cuts, but the expense of the finishing process which is made up of light cuts, grinding, scraping, etc.

The maximum cutting speed will vary greatly, depending upon the material being turned; the hardness of the metal; the depth of cut and width of feed, and the diameter and length of the work.

The cutting speed and the rate of feed for roughing work should be as great as the conditions will admit of, and should be such that a correctly formed tool will last a reasonable length of time between grindings. What this time should be will depend on the facilities at hand for keeping the tool in shape. As the object of a roughing cut is to remove the surplus metal as quickly as possible, there is no objection to removing the tool for grinding, provided time is saved. The maximum amount

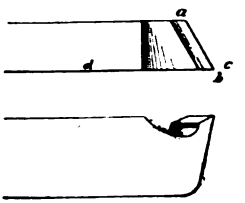


Fig. 50

of work may be turned out either by a low-cutting speed and heavy feed, or by a high cutting speed and lighter feed. Probably in the majority of cases the former method will result in the greater output.

In the case of finishing cuts, the tool should carry the cut the full length of the piece without re-grinding on account of the difficulty of re-setting the tool to cut to the exact diameter. This does not mean that finishing cuts must be taken at a slower cutting speed, for, in many cases, as the cut is light, the speed may be

increased. The speed should be such that the tool will carry the cut the full length of the piece if it can be done in less time than the tool can be ground and re-set.

The following table gives average cutting speeds which may be easily maintained with properly formed common steel tools.

CUTTING SPEEDS.

Wrought Iron and Soft Steel.

Diameter of Work.	Roughing Cut, Speed.	Finishing Cut, Speed.
½	40	40
1	35	35
1½	30	30
2	28	28
2½	28	28
3	28	28
4	26	27
5	25	27
6	25	25
	Tool Steel.	
½	24	24
¾	20	20
1	20	20
1½	18	18
2	18	18
3	18	18
4	18	18
	Cast Iron.	
1	45	45
2	40	40
3	35	40
4	35	40
5	30	35
6	30	35
	Brass.	
½	120	120
¾	110	110
1	100	100
1¼	90	90
1½	80	80
1¾	80	80
2	75	75
2½	75	75
3	70	70
3½	70	70
4	70	70
6	65	65

With high speed tools on roughing cuts the obtainable speeds will be somewhere between the limits given below, depending on the depth

of cut and rate of feed, the first figure in each case being for a cut $\frac{3}{8}$ inch deep with a feed of $\frac{1}{64}$ inch, and the last figure for a cut $\frac{3}{4}$ inch deep with a feed of $\frac{3}{16}$ inch.

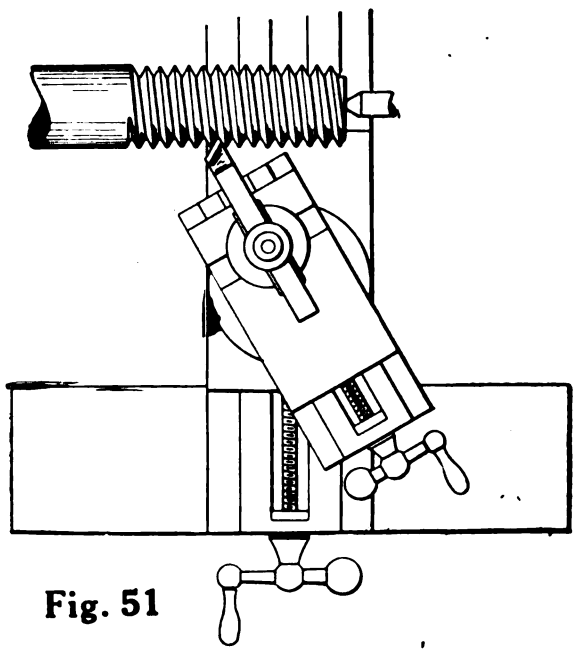


Fig. 51

Soft cast iron	239	to	40	feet	per minute.
Medium cast iron	119	"	20	"	" "
Hard cast iron	70	"	12	"	" "
Soft steel	518	"	93	"	" "
Medium steel	259	"	46	"	" "
Hard steel	118	"	21	"	" "

In grinding high-speed steels care must be used not to over-heat the tools, and especially

not to cool them off in water while grinding, as this has a tendency to produce cracking of the cutting edge. This does not apply to wet-tool grinders.

Making Fits.

In general shop work the machinist will be called upon to make four kinds of fits, as follows: working, or running fit; driving fit; press, or forced fit; shrink fit.

A running fit requires that the difference in the diameter of a shaft and its bearing be sufficient to allow the shaft to turn freely in the bearing and admit oil, but without any great amount of lost motion. This difference in diameter will depend on the diameter of the shaft, the length of the hole and the condition of the surfaces. For a small spindle the allowance may be as little as 0.0005 inch, while for a shaft 10 inches in diameter the allowance would be from 0.005 inch to 0.01 inch.

A driving fit requires that the bolt or shaft be slightly larger than the hole into which it fits, and the difference in diameter will depend on the diameter and length of the work as well as the condition of the surfaces and the desired tightness of the fit. For small, smooth work, the allowance should be from 0.0005 inch to 0.001 inch, while if the work is rough the allowance would be increased to 0.002 inch to 0.003 inch.

Where the work is of large diameter, and is to be forced together by means of a hydraulic press, as in the case of crank pins and axles,

the allowance for the fit will be from 0.001 inch to 0.002 inch for each inch in diameter, depending on the condition of the surfaces, the trueness of the holes and the length and thickness of the hub.

In putting pieces together by driving or forcing the surfaces must be well lubricated, otherwise they will cut and stick fast before reaching the proper position.

Where pieces are to be fastened together by shrinkage the allowance is generally greater than for forced fits. For small work the allowance should be about 0.003 inch for the first inch of diameter, adding 0.001 inch for each additional inch. The allowance for locomotive tires is $\frac{1}{80}$ inch per foot of diameter for wheel centers less than 66 inches in diameter, and $\frac{1}{60}$ inch per foot of diameter for centers 66 inches and over in diameter.

CHAPTER XX.

MACHINE WORK—PLANER AND SHAPER WORK.

For machining plane and irregular surfaces that may most conveniently be cut by a tool moving across the work in a straight line, the planer and shaper are used.

The common form of planer is shown in Fig. 1. It consists of the bed *a*, the upper surface of which is provided with two V-shaped guide ways on which the work carrying table, or platen *b*, is moved back and forth in a straight line. This bed has two upright frames, or housings, *c*, firmly bolted to it, the front and side surfaces of which stand at a right angle to the line of travel of the platen *b*. These housings carry the cross slide or cross rail *d* to which is fitted the saddle *e*, carrying the head *f*, to which the tool is secured by means of the tool clamp *g*.

The cross rail *d* is adjustable in a vertical direction by means of two vertical screws operated by the bevel gears on shaft *m*. This shaft is rotated by the handle *n*. To secure *d* at the adjusted height suitable devices are provided for clamping it firmly to the face of the housings.

The faces of the cross slide are parallel one to the other and stand at a right angle to the V-shaped guides on which the platen *b* slides;

hence the cross slide will be parallel with the platen at whatever height above the platen it is set, provided the elevating screws lift each end of *d* equally.

The construction of the head *f* is similar to that of a compound rest on the lathe, having in addition the tool box and apron. This head is

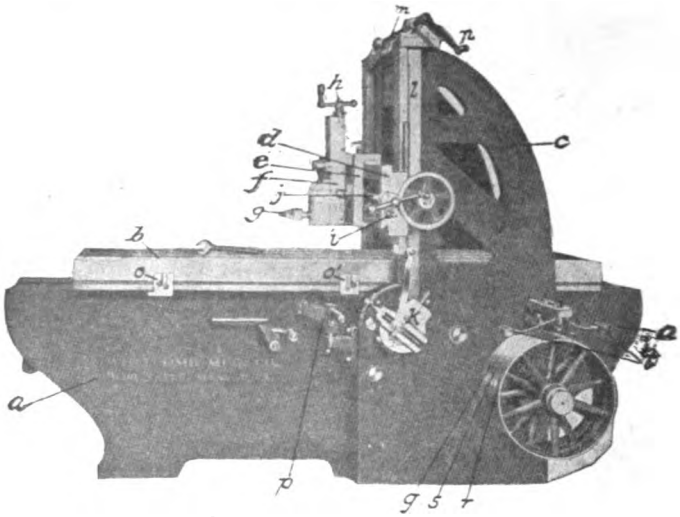


Fig. 1

secured to the saddle *e*, that is securely gibbed to the cross rail upon which it travels. The vertical feed of the tool is secured by operating the handle *h*, and also automatically by means of the splined feed shaft *j*, and gears shown.

The horizontal tool feed is secured by moving the saddle on the cross rail by means of the lead screw *i*.

The mechanism for moving the platen *b* varies in different planers, but generally consists of a rack on the bottom of the table meshing with a train of gears driven by the driving pulley *s*. Two belts are used, one for the forward, or cutting stroke, and one for the reverse. These belts are shifted alternately from the loose pulleys *q* and *r* to the driving pulley *s*, by

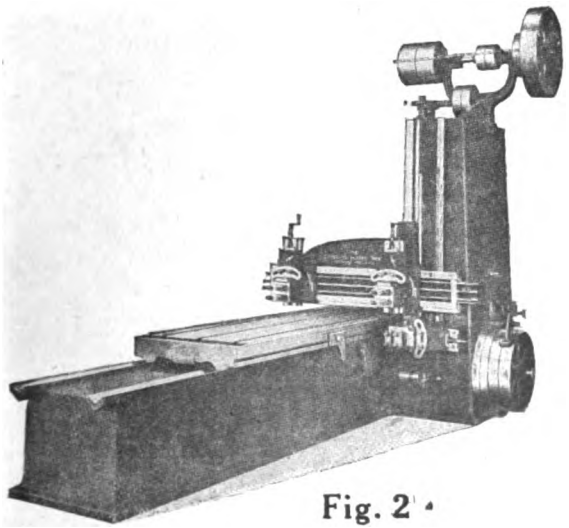


Fig. 2.

the belt shifters *t*. These belt shifters are operated by suitable mechanism connected with the shifting handle *p*, this handle being operated by the shifting dogs *o* and *o'*. These dogs may be placed in any position along the table, thus regulating the length of the stroke and the portion of the platen passing under the tool.

The automatic feed motions are operated by the friction disc *k*, which is moved through about one-half a revolution when the motion of the table is reversed. This disc has a slide way on its face in which a block is fitted, which block may be moved to or from the center by the screw shown, thus varying the amount of

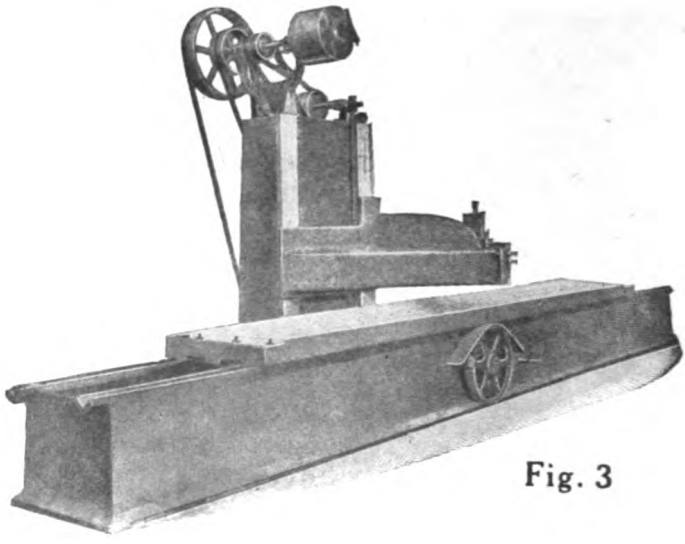


Fig. 3

stroke imparted to the rod which moves the feed rack *l*. The motion of this rack is transmitted by suitable gears and ratchet mechanism to the feed rods *i* and *j*.

Planers are often fitted with two heads on the cross rail, and also with heads mounted directly on the face of the housings, thus increasing their capacity.

The size of a planer is designated by the width between the housings, the height the tool can be raised above the platen and the greatest length of table motion that can be utilized while the tool is cutting. Thus a 36″x36″x10 ft. planer would be one measuring 36 inches between the housings; the tool could be raised 36 inches above the platen and the table has a working stroke of 10 ft. maximum.

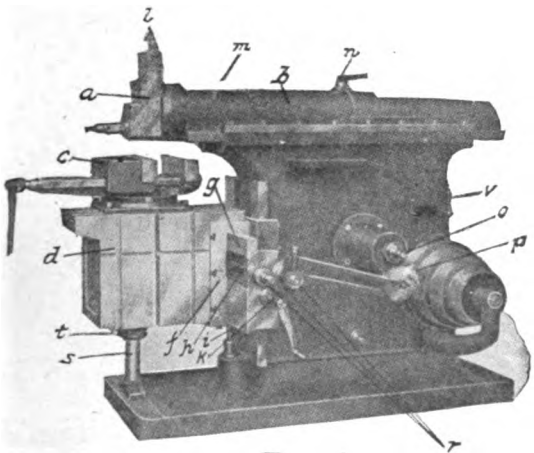


Fig. 4

Figs. 2 and 3 show two views of an open side planer having three heads. It will be noticed that in this planer the cross rail is supported from two housings placed on the same side of the machine, thus leaving one side clear. This form of construction greatly increases the capacity of the machine for some kinds of work.

Fig. 4 shows the common type of crank

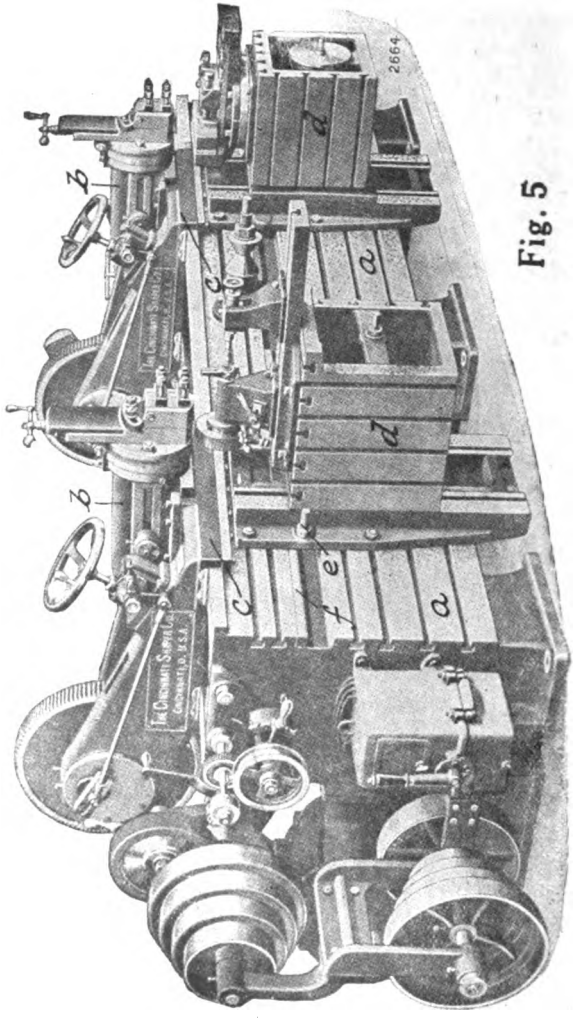


Fig. 5

shaper which is used to a greater extent than any other form. The tool is clamped in the head *a* attached to the ram *b*. The ram is reciprocated across the work which is held in the vise *c* or bolted to the top or side of the table *d*. The table is bolted to the saddle *f*, which by means of screw *h* is given a lateral movement on the cross slide *g*. Cross slide *g* is gibbed to the face of the base of the machine and has a vertical movement controlled by screw *i*, operated by a pair of bevel gears from shaft *k*. From the foregoing it will be seen that

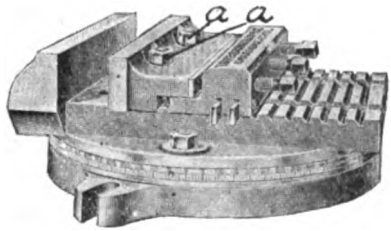


Fig. 6

the work table *d* has a lateral movement in a plane parallel to, but at a right angle to the line of motion of the ram *b*, and also has a vertical movement in a plane at a right angle to the line of motion of the ram.

The head *a* has a vertical movement controlled by handle *l*, and is constructed so that it may be swiveled around in a vertical plane for the purpose of machining angular surfaces.

The length of the stroke of the ram is adjusted by means of the shaft *o*, and the position of

the ram relative to the work is adjusted by operating shaft *m*. Handle *n* is for clamping the ram in any adjusted position.

The lateral feed of the table is given by the adjustable crank *p* and train of gears *r*. Handle *v* at the back of the machine is for throwing the back gears in and out of gear.

Fig. 5 shows a traveling head shaper which is used quite generally in railway shops. The bed *a* is made in the form of a box and is very rigid. The rams *b*, *b* are carried in saddles *c*, *c*, which are securely gibbed to the top of the bed, and have a horizontal movement at right angles

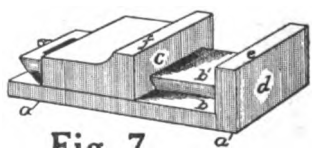


Fig. 7

to the line of motion of the rams. The tool is fed across the work by moving the saddles.

The work holding tables *d*, *d* are stationary while the tool is at work, but may be moved to any position along the bed. This movement is secured through a pinion on shaft *e* meshing with the rack *f*. The tables also have a vertical movement. In other respects the construction is similar to that of the shaper shown in Fig. 4.

While the planer and shaper differ radically in construction and operation, the methods employed for holding the work are similar, and in the matter following, the description of work-

holding devices will apply equally to either machine, unless otherwise specified.

The simplest method of holding work in the shaper or planer is by means of a vise. A common form of planer vise is shown in Fig. 6, while the shaper vise is shown at *c*, Fig. 1. The only real difference in these two devices is in the manner in which the vise is operated. By reference to Fig. 1, it will be seen that the work is clamped in the shaper vise by operating one screw with a suitable handle. In the vise shown in Fig. 6, the clamping is done by operating the three square head screws. Either of these vises

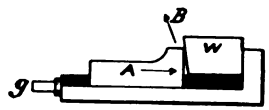


Fig. 8

may be set in any angular position on the table, and generally the base is graduated in degrees for convenience in setting.

Fig. 7 shows a plain shaper vise, or chuck. The bottom surface *a*, *a* is parallel with the surfaces *b* and b^1, and as surface *a* is secured to the top of the table, and this top is parallel with the line of motion of the ram *b* (Fig. 1), and also parallel with the cross slide *h*, it follows that the face b^1 of the chuck is also parallel with the line of motion of the ram and the cross slide.

The surfaces *c* and *d* of the vise which grip the work are finished at a right angle to the surface b^1, therefore the upper surface of work

that beds fair on b^1, or beds fair against c and d, will be held parallel to the line of tool traverse and also parallel to the line of longitudinal feed traverse. The top surfaces e and f of the vise jaws are also parallel with surface a, and therefore form guides by which to set the work. Generally, the movable jaw is provided with bolts a, a (Fig. 6), to prevent its lifting away from the face of the slide when tightened.

In holding work in shaper or planer chucks the following points should be considered.

As the face d of the fixed jaw is finished at right angles to the line of tool traverse, this

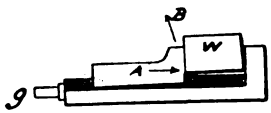


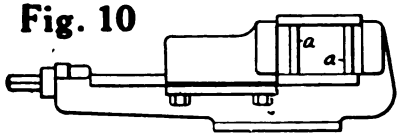
Fig. 9

face and the surface b^1 should be used as guides in setting the work. Referring to Fig. 8, it will be seen that the work is held in the jaws by the pressure exerted by the screw g, the pressure being in the direction of the arrow A. The movable jaw will tend to lift in the direction of the arrow B, and in case the edges of the work W bearing against the chuck jaws are not parallel, it will be very difficult to get the under surface of the work to bed fairly on the upper surface of the chuck. If a piece of work shaped like that shown in the figure is placed in the chuck, it will take the position shown in Fig. 9, and the top face will be machined out of square

with the other surfaces. From the foregoing it will be seen that the face *d* of the fixed jaw is to be depended on in setting the work, and the surface of the work which is to form a guide for the chucking should be placed against this surface.

In the case of thin work where the amount of surface bearing against the jaw is small as compared to the width between the jaws, the wide surface should be machined first, as this will give a true surface of sufficient area bedding against the chuck jaw so that the edges will be machined square with this face. Work of this character should be set in the chuck by using

Fig. 10



parallel pieces *a*, *a*, as shown in Fig. 10. Where the edges of such work are so rough that they will not bed fair on the chuck jaws, pieces of copper or lead wire placed between the jaws and the work will hold it securely.

Where the work has a projection which will prevent the chuck jaw from meeting the work fairly, short pieces, as shown at *a*, in Fig. 11, should be placed between the movable jaw and the work.

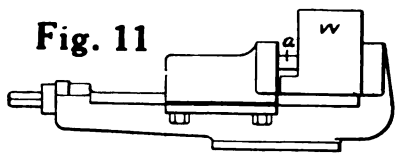
When the work is very thin, and so narrow that it cannot be bedded directly on the chuck bottom, it is best set by using a surface gauge, or calipers, as shown in Fig. 12 (*a*) and (*b*).

Where possible, the work should be so placed in the chuck that the tool will travel across the longest dimension in making the cut.

The following examples will show the correct method of handling work secured in the chuck.

Fig. 13 shows a rectangular piece which is to be machined all over. In order to allow the tool to travel the long way of the work the vise should be set at right angles to the position shown in Fig. 4. The work should preferably be roughed out all over before any finishing cuts are taken. The piece is first secured in the chuck and a cut taken over one side, then given

Fig. 11



a quarter of a turn so that the planed surface will bed against the fixed jaw of the chuck. At this setting care must be taken that the planed surface beds fair on the fixed jaw (if this jaw is perpendicular to the table). If the surface of the work in contact with the movable jaw is not true, difficulty will be experienced in holding the finished side square against the fixed jaw. Suppose the work is tapered as shown in Fig. 14 (*a*), the surface *a* being finished while the surface *b* is rough and not parallel to *a*. When the chuck is tightened the pressure will come at the top edge of the jaws and the work will be canted over more or less so that surface *a* will

not bed fair against the fixed jaw *C*. If this is found to be the case it may generally be overcome by placing a round rod or wire between the work and the movable jaw, as shown in Fig. 14 (*b*). This will allow the work to turn slightly and face *a* will bed fair against jaw *c*. The rod or wire should be as long as the work in case the work is shorter than the chuck jaws, and as long as the jaws in case the work is longer than the jaws.

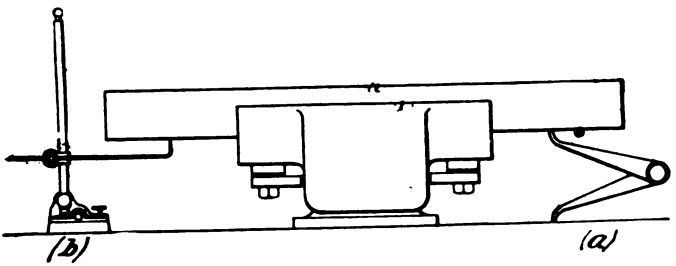


Fig. 12

Another point to look out for is the raising of the movable jaw when tightened, as shown in Fig. 9. This will occur to some extent even if the work is perfectly square, and is prevented by tightening the bolts *r*, *r*, Fig. 14, before the jaw is tightened.

If the work projects beyond the chuck it is well to test the finished surface by using a square from the table as shown in Fig. 15.

In order to get the opposite sides of the work parallel the piece may be set on parallel strips, as shown in Fig. 10, bedding it firmly onto the strips by striking the top surface with a soft

hammer, or block of wood. If the work extends beyond the chuck it may be set parallel to the table by using calipers between the table and the under surface, or by using a surface gauge, as shown in Fig. 12 (*a*) and (*b*).

In shaping a tapered piece, as a key, a line is generally scribed on the work and this line is set parallel to the table by means of a surface gauge. Where a number of tapered pieces are to be finished they are set in the chuck, as shown in Fig. 16, the finished edges resting on parallel

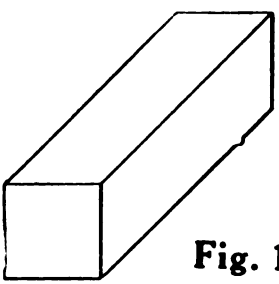


Fig. 13

pieces, as shown, the pieces *a*, *a* being adjusted until the line *b*, *c* is parallel to the table. These pieces insure that the lower edges are in line and care must be taken to see that all of the pieces bed fairly on the parallel strips which should, of course, be somewhat shorter than the total thickness of the keys. Where much work of this character is done, the use of the chuck is dispensed with, the pieces being held in a suitable "jig" which insures the correct setting.

If a taper piece, as a key, is to have the side

faces machined and the chuck has no provision for setting the movable jaw at an angle with the fixed jaw, it may be held, as shown in Fig. 17. *A* is the key with the trued edge against the fixed jaw *b*. At *c* is a piece placed between the key and the movable jaw to compensate for the taper of the key. In placing the piece *c*, the key should be gripped just enough to hold it, and piece *c* is then pushed into place firmly with the fingers and the chuck tightened.

Round work may be held in the chuck provided the height of the jaws is equal to, or

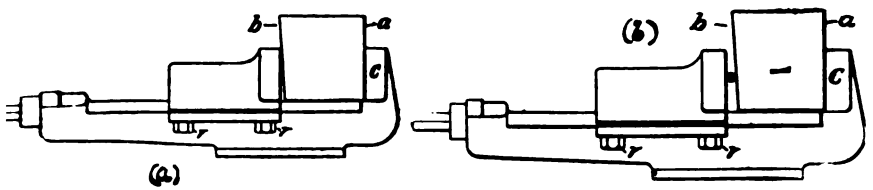


Fig. 14

greater than the radius of the work, but the safest way to hold this work is to clamp it to the table, as will be described later.

Sometimes difficulty will be experienced in holding thin work in the chuck. This may be accomplished by using toe dogs, as shown in Fig. 18. These dogs are small pieces of steel pointed at both ends. The figure shows the application fully, so that further description is unnecessary. The dogs should be so placed that the angle they make with the bottom of the chuck will not exceed 15°.

Work which is too large, or which for other reasons cannot be conveniently held in the chuck, is secured to the face of the table by bolts and clamps. Fig. 19 shows a plate clamped to the table with two clamps. As the clamps, unless unduly tightened, offer little resistance to the pressure of the cut, stop pins, at *a*, *a*, or a piece firmly clamped to the table, should be used to prevent the longitudinal movement of the work. The clamps should be so adjusted that the bolts will come as close to the work as possible. Also the blocks or

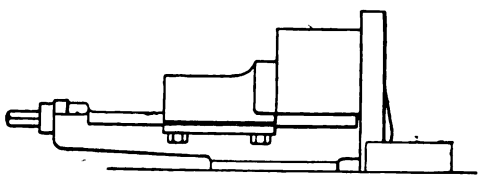


Fig. 15

packing pieces should be the same height as the work, or slightly higher, for the same reasons as were given under the remarks devoted to lathe face plate work.

Bolts for clamping purposes must have heads which will fit in the T slots in the table. A more convenient arrangement is to make a number of T blocks, as shown in Fig. 20, and use studs of proper length. The T blocks should be case hardened. They are easily made and will pay for themselves in a short time.

The most convenient clamp for general use is the common "horse shoe" clamp, shown in

Fig. 21. These clamps are made of a bar of square iron bent in a U shape with the opening wide enough to slide over the shank of the clamp bolt.

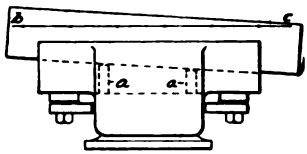


Fig. 16

For work that is to be finished all over and which is of such shape that there is no place to put clamps without covering a part of the surface to be machined, it will be necessary to machine a part of the surface and then change

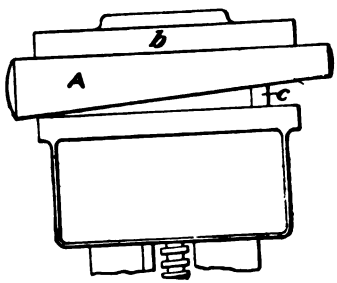


Fig. 17

the clamps to the finished surface, then finish the cut, or make use of some of the various forms of finger and toe clamps.

Fig. 22 shows a piece of work held by a finger clamp. This clamp has one end forged or turned round to fit loosely in a hole drilled in the work.

In the absence of these clamps the same result may be accomplished by placing short pins in the drilled holes and placing a common clamp on the pin, as shown in Fig. 23.

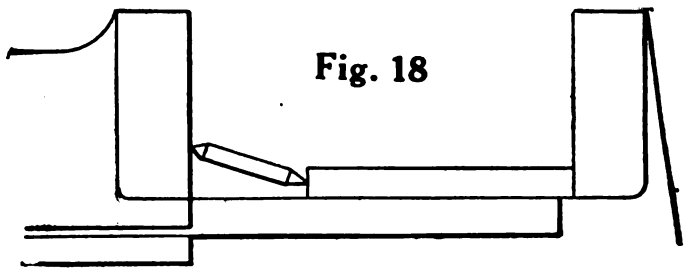


Fig. 18

Two forms of toe clamps, or more correctly speaking, toe dogs, are shown in Fig. 24. The one consists of a short piece of steel pointed at both ends. It may, however, be made with one end cupped. The other style is made with

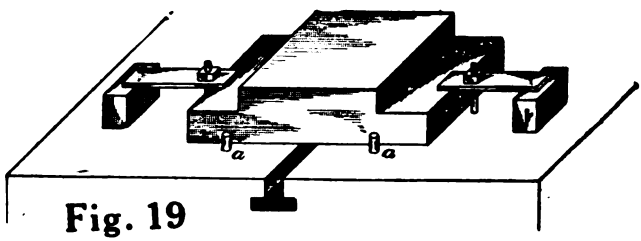


Fig. 19

one end flattened to press against the work, the other end being pointed or cupped to receive the set screw of the screw plug, shown in Fig. 25. One form has one end turned to fit the holes in the table, the other end being left square, and is tapped for the set screw. The

other form is made to fit the T slots. In the figures the ends of the set screws are shown pointed, in which case the end of the dog must be cupped. If the set screws are cupped, the end of the dog should be pointed.

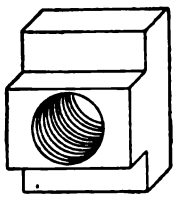


Fig. 20

Fig. 26 shows the method of holding work with these dogs, a number of them being placed on each side of the work. The slant of the dogs should not be too great, or the pressure of the set screw will tend to turn the outer end

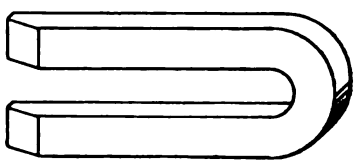


Fig. 21

upward about the end in contact with the work. The angle they make with the table should not exceed about 15°.

As these dogs have very little tendency to hold the work in the direction of the cut, it

will be necessary to use stop pins in front of the work.

Sometimes it may be advisable to clamp a strip on the shaper or planer table for one edge of the work to abut against, using the toe dogs on one side only. This is shown in Fig. 27.

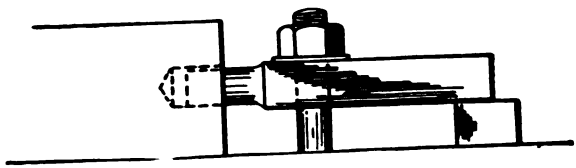


Fig. 22

Another very convenient clamp for holding work that is to have the top surface machined, and whose form will not permit the placing of common clamps, is the toe clamp shown in Fig. 28. These clamps are made of a flat piece of steel of suitable width and thickness, bent

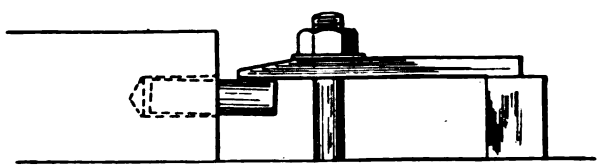


Fig. 23

in the form shown. Their application is shown in Fig. 29, which shows a driving box wedge set to have the top surface planed to the line laid out by the machinist putting up the shoes and wedges. The shoe or wedge is shown

at *a;* the stop pins to hold the clamps from moving end ways at *b*, *b*; *c*, *c* are the clamps and *d*, *d* the clamp bolts. It will be seen that any tightening of the clamp bolts will not only force the work firmly down on the table but will also prevent any end movement. The clamps should be so adjusted by suitable packing pieces between them and the stop pins that the ends at *e* and *f* will come at about the same height on the work. In the particular example the wedge must be so set that the points

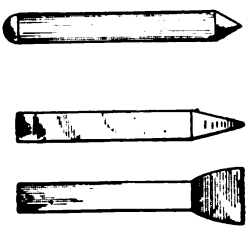


Fig. 24

g, *g* and *h* (on the opposite side) will be parallel to the table. This is most easily accomplished by first placing the wedge on the table and taking out any "rock" there may be, by placing suitable shims under the corners as may be necessary. Then place the clamps in position and tighten. The two points *g g* should be tested with a surface gauge, and if not the same height the low end should be raised by placing a suitable shim clear across the low end. Suppose the point *g*, at the right hand end, is too low; if the clamp at this end is loosened,

leaving the other one tight, the loose end will raise clear of the table and the shims may be easily placed under the end. After the points *g g* are made parallel to the table, point *h* on the opposite side should be brought to the same height by placing equal shims under each corner on that side. A shoe or wedge can be leveled up in this manner in much less time than it takes to describe the process.

Round work may be clamped to the table as shown in Fig. 30, the shaft being placed in one of the T slots and the clamps applied as

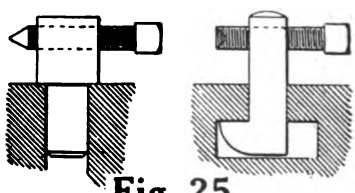


Fig. 25

shown. A better method is shown in Fig. 31, where *a* is an angle iron bolted to the table, the shaft being held by means of the screw plugs *b*, piece *c* and packing block *d*. The angle iron is beveled as shown so that the pressure exerted by the screw plugs forces the shaft down onto the table firmly.

For holding certain classes of work the V blocks shown in Fig. 32 are necessary. These blocks are generally made in pairs and have a tongue *a*, which is fitted to the slots in the table. The Vs should be out at the same time to insure both blocks being exactly alike, and in case

the Vs are not cut exactly central with the tongue, care must be used in setting the blocks, otherwise the axis of the work will not be held parallel to the line of tool travel.

Fig. 33 shows the application of these blocks in planing a crosshead. The crosshead is mounted on a mandrel (or the piston rod may

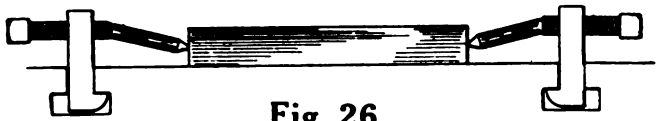


Fig. 26

be used) and set perfectly square cross ways of the table by means of the double-headed jack shown. The top surface of the crosshead is planed, after which the crosshead is turned over and the under surface and the wings planed. The wings must be planed exactly central and the finishing cut across the bottom faces should be taken without moving the tool.

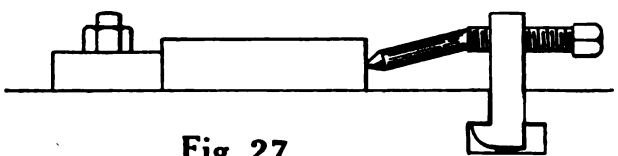


Fig. 27

Fig. 34 shows a valve yoke set up for planing, the surface of which rests on the valve. As this surface must be in a plane parallel to the axis of the stem, V blocks must be used in the setting. This figure shows a special form of V block designed especially for this work. It

consists of a piece of cast iron of suitable length and height, having a V groove planed lengthwise. The stem is clamped in the V block and the yoke leveled by means of the wedges, after which the toe clamps are applied as shown. The whole surface of the yoke may be planed at this setting, or after planing the sides *a* and *b* the yoke may be turned one-fourth around and the ends *c* and *d* planed. Which method will be the better will depend on circumstances.

For some classes of work various forms of

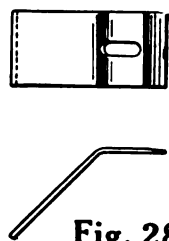


Fig. 28

angle plates are necessary. Fig. 35 shows the common form. The two faces *a* and *b* are planed so that they make an angle of 90° with each other. When in use one face is bolted to the table and the work is secured to the other face. In the figure a connecting rod brass is shown bolted to the plate in order to have the inside of the flanges planed to fit the strap. After finishing the flanges *c* and *d*, the brass is given a quarter of a turn, bringing up flanges *e* and *f*. The finished edges of flanges *c* and *d* must be set at right angles to the table by using

a square. This operation is repeated until the brass has been machined all around.

For this class of work some shops use a special angle plate having a supplementary plate rotating on a stud, as shown in Fig. 36. *A* is the angle plate; *B* the supplementary plate

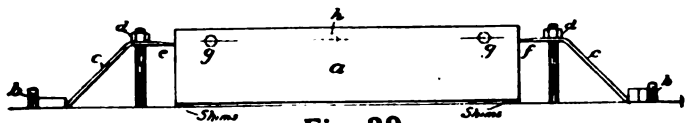


Fig. 29

secured to *A* by means of the stud *a* and nut *b*. Plate *B* has four holes, *c*, *d*, *e* and *f*, spaced exactly 90° apart, into which the taper pin *C* enters, thus accurately locating the position of plate *B*. The work is held to *B* by means of a clamp and the stud *g*. In the case of a rod

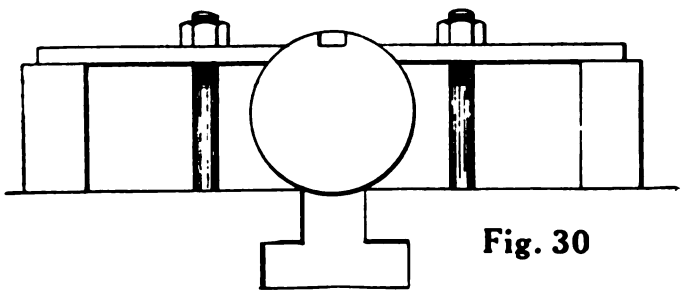


Fig. 30

brass secured to *B*, after finishing one set of flanges with pin *C*, in hole *c*, if the pin is withdrawn and *B* is rotated until the pin enters hole *d*, the work will have been turned through an angle of 90°. By using an angle plate of

this kind it will be necessary to set the work but once.

Fig. 37 shows a special form of double angle plate, designed for holding eccentrics while planing the tongue and groove. As will be seen, the angle plate has a tongue which fits into the center slot in the planer table, thus keeping it central. The eccentric halves are supported by hard wood blocks and are leveled up by wedges. At each eccentric half, a $\frac{7}{8}$ inch bolt is passed through the angle plate and the $2\frac{1}{2}''$ x $1\frac{1}{4}''$ clamping strip, and the eccentric

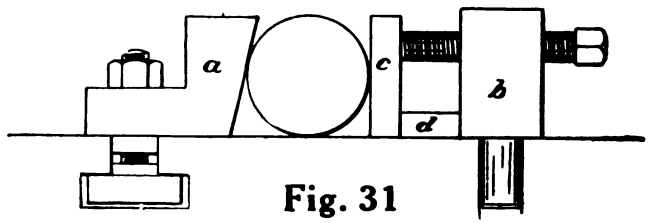


Fig. 31

halves are further secured by two $\frac{3}{4}$ inch set screws passing through the clamping plate.

This form of double angle plate is also used for holding driving boxes, truck boxes, etc.

For holding some kinds of work on the shaper or planer table, the use of special jigs will save time. The application of a jig for the planing of driving box shoes and wedges is shown in Figs. 38, 39 and 40.

The particular jig shown is designed to hold two shoes or wedges, and enough of the jigs should be made to fill the planer table, as the maximum output will be secured by machining

the largest possible number at one setting. This method of constructing the jigs has the advantage that the jigs are not excessively heavy and may be handled easily.

The shoes *A A* are first clamped in the jigs, as shown in Fig. 38, being held by the inclined set screws *a a*. End movement is prevented by the stop plate *b* held by the studs *c c*. The top surface is planed, after which the jigs are removed from the table and the shoes placed in

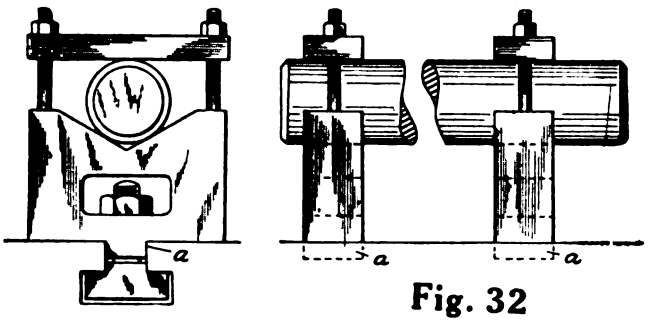


Fig. 32

two rows upon parallel strips, as shown at *a a*, Fig. 39, being held to the table by clamps at *b*, *c*, *d*, etc. The outside surfaces *e* and *f*, and the tops *g g* of the flanges, are planed, using both planer heads or a special tool similar in design to the one shown in Fig. 41, except that it is designed for cutting outside surfaces instead of inside. For the third and last operation the jigs are again placed on the table and the shoes or wedges secured, as shown in Fig. 40. They are held by the clamps *a*, *b* and *c*, also the set screws. The dummy wedges *W W* are secured

to the jig in order to plane the wedges to the correct angle. The inside edges of the flanges are planed by using a special tool, shown in Fig. 41. This tool has two tool blocks holding square tools which may be adjusted to cut to the required width.

After planing in this manner the shoes and wedges are ready to be fitted to the frames of the locomotive and are marked off for final planing. They are then sent to the machine, where they are planed to the lines laid out and have the corners rounded. For doing this part

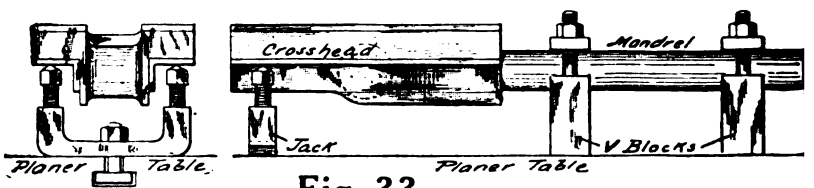


Fig. 33

of the work a special chuck similar to that shown in Fig. 42 is used.

This chuck consists of a base, or chuck body, *A*, which is secured to the planer table by means of bolts through the lugs *a* and *b*. The tongue *c* fits in the T slot of the table and insures the longitudinal alignment of the chuck. At *d*, *e* and *f* are three $\frac{3}{4}$ inch set screws for adjusting the lines on the shoe parallel to the planer table. The movable jaw *B* is held to the body by two $\frac{5}{8}$ inch T head bolts *g g*, which move in suitable slots in the base. This jaw is forced against the work by the two $\frac{3}{4}$ inch screws *h h*. A shoe in position to be planed is shown by the dotted

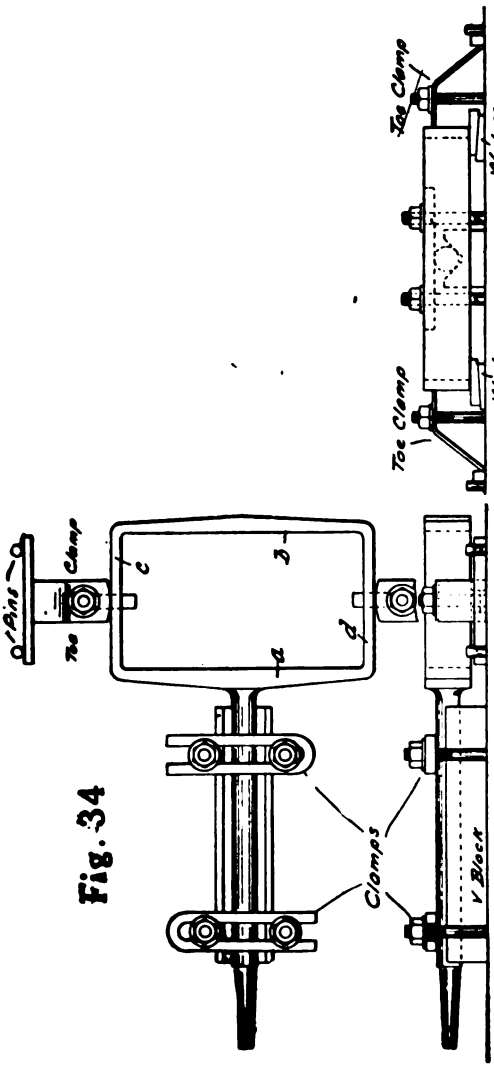


Fig. 34

lines in the right hand view of the figure. A chuck of this description is a very convenient tool for this class of work. In the absence of this chuck the shoes and wedges may be held as shown in Fig. 29.

Work held in the chuck which projects a considerable distance from the chuck, or work bolted to an angle plate where the overhang is considerable, should be supported from the table by using small jacks. Fig. 43 shows a

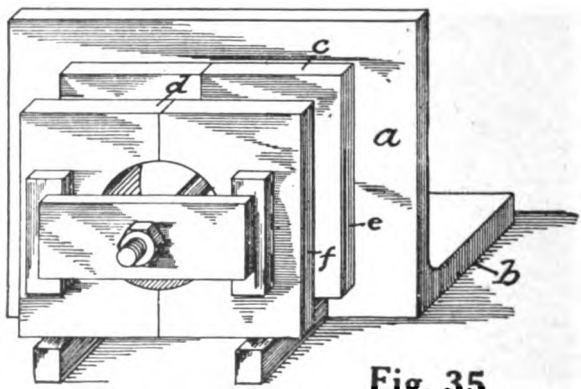


Fig. 35

guide bar held in the chuck, having the ends supported by jacks. Fig. 44 shows a cylinder casting set up for planing, being supported by V blocks and jacks. This figure also shows the application of struts to the work for the purpose of resisting the pressure of the cut.

In planing cylinders, the various steps are about as follows: The cylinder is placed lengthwise of the bed, as shown in Fig. 44, resting the

turned portion of the flanges on V blocks *a a*. A center *b* should be accurately located in each end of the cylinder and these centers set exactly the same distance from the table and exactly in line with the tool traverse lengthwise. The inside surface *c c* should be set square with the planer table by means of the jacks *d d*, and firmly clamped, about as shown. The disposition of the clamps *e e* and struts *f f* will depend largely on the construction of the cylinder and the position of the T slots and

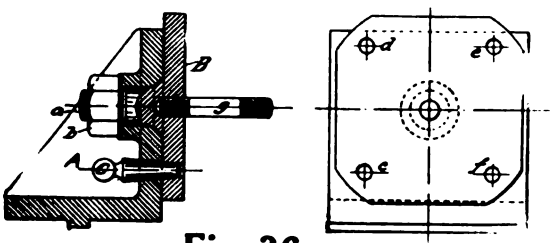


Fig. 36

holes for bolts and stop pins in the planer table. The inside surface *c c* is planed so that the distance from the center of the cylinder to the surface is equal to one-half the width of the cylinders from center to center. The top of the cylinder at *g* and *h* for the steam chest seat is then planed. The cylinder is now turned around one-quarter of a turn and the planed joint surface *c c* set square, vertically with the table. The cylinder centers *b b* are lined square across the table, using a square from the centers to a square line on the table. At this setting the valve seat *i* and the end joints *k* for the

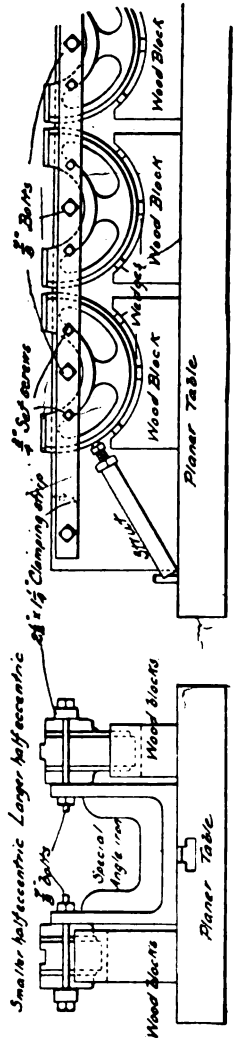

Smaller half eccentric
Larger half eccentric
Wood Blocks
Special Angle Iron
Planer Table
Wood Blocks
Planer Table
Wood Block
Wood Block
Wood Block
Planer Table

Fig. 37

steam chest are planed. The cylinder is now turned over and the bottom at *l*, where the center casting is bolted on, and the frame fit at *m* and *n* planed the correct distance from the cylinder centers. Too much care can not

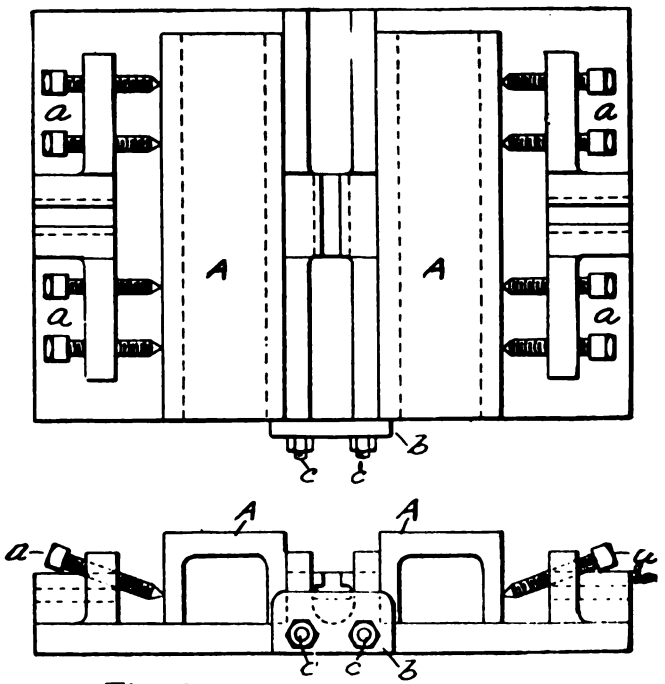


Fig. 38

be used in getting these various settings absolutely correct.

In planing the stub ends of connecting and parallel rods, a center line should be scribed at both ends of the rod and on both edges, as shown

at *a*, *a* and *b*, *b*, Fig. 45. The rod should be set on the planer table so that these four lines will be the same distance from the table when tested with a surface gauge. If this cannot be done the rod is twisted and should be straightened before attempting to plane. To plane the edges of the stub ends, the rod body should be centered on the sides as shown at *c c* and *d d*, Fig. 45, and set as before. Unless the stub ends are planed absolutely central with the body

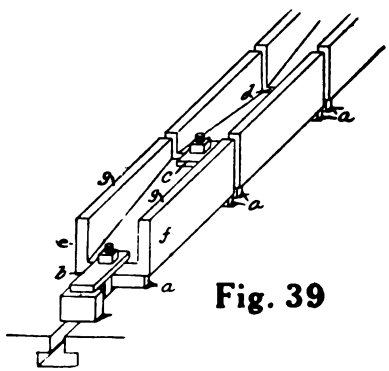


Fig. 39

of the rod, and also exactly in line lengthwise, all kinds of trouble will be experienced in fitting the brasses to the pins. The rod may best be clamped by using screw dogs or toe clamps.

Rod straps are first planed on the sides and then bolted to an angle plate to plane the edges. Generally sufficient stock should be left on the sides to allow the straps to be finished to size after they are bolted to the rod. This, for the reason that it is a difficult matter to hold the strap absolutely in line with the rod while

reaming the holes. The inside of the straps is generally machined on a slotter or milling machine.

Driving and engine truck boxes are planed by clamping on the planer bed and truing the hub face, then turned over and the back face finished, making the distance from the center of the shoe and wedge bearing correct. The boxes then go to the slotter to have the fit for the brass and cellar machined, after which the brasses are fitted and the boxes returned to the planer to have the shoe and wedge fits machined. To do this the boxes are clamped

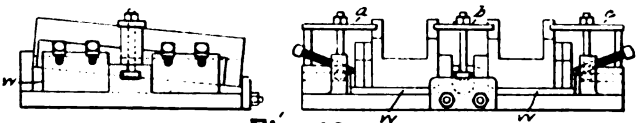


Fig. 40

to an angle plate or special jig, one form of which is shown in Fig. 46. This particular jig holds two boxes and consists of a base plate *A*, which is bolted to the planer table, the jig proper *B* being pivoted on this base plate so that it may be set at any required angle. The boxes are clamped to the jig by means of the long stud *a*, and are adjusted for height by means of the adjusting screws *b*, *b*, *b*, *b*. They are also clamped front and back by clamps and bolts through the slots *c*, *c*, *c*, *c*. If the flanges are to be planed straight the jig is set central on the base plate, a suitable mark on the jig and base plate being provided. If the flanges are

to be planed taper, they are first planed straight, then the jig is set off center the required amount and the flanges from *d* to *e* planed, after which the jig is set off center the same amount in an opposite direction and the flanges from *f* to *g* planed. The shoe and wedge fits should be planed central with the brass and the flanges made the correct thickness measuring from the face of the box bolted to the jig. The boxes are

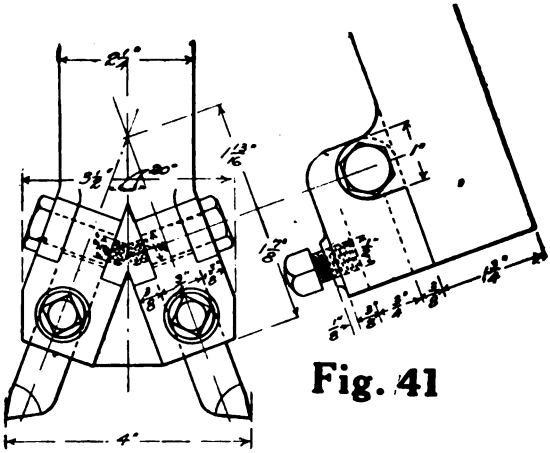


Fig. 41

now turned over, clamping the same side to the jig as before, and the other side finished, being particular to see that the flanges are the same thickness as those on the opposite side.

To plane a slide valve it should first be clamped face down on the planer table and the top trued up. Then turned over and the face finished. It should then be centered at each end and clamped face down on parallel strips, setting

the centers at each end true with the edge of the table. It should now be faced off to the correct height and the sides where the yoke fits and the outside edges planed to the required size, using care that they are planed central.

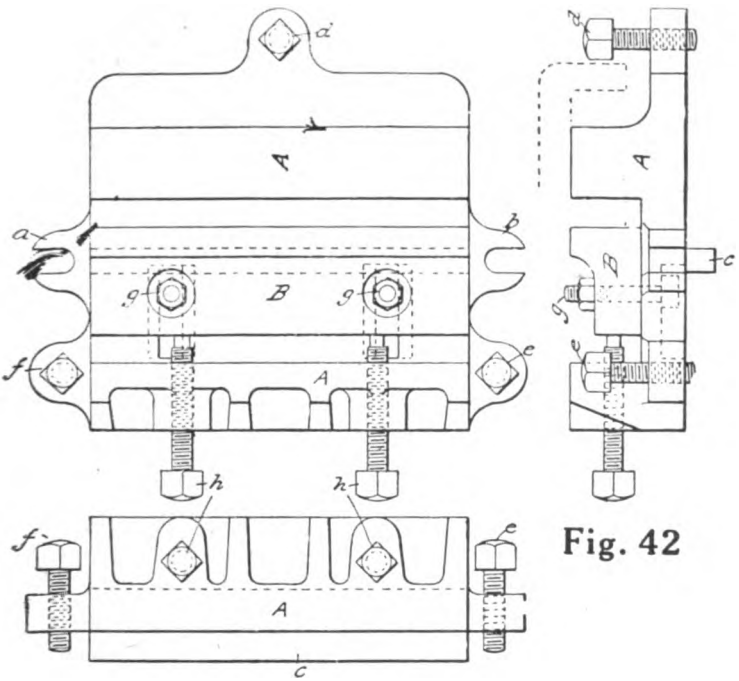


Fig. 42

The bottom flanges should be planed to the correct thickness. The two grooves for the long packing strips (if the valve has the Richardson balance) should be cut the correct width and depth and right distance apart, with a square nose tool, keeping these grooves central. The

valve should now be set cross ways on the table on parallel strips, setting it perfectly square. The ends should be planed the correct length and central with the exhaust cavity and the grooves for the end packing strips cut. The edges of the exhaust cavity may be machined in the slotter or milling machine, or if done on the planer these edges should be laid out and a clearance space for the tool at each end chipped out, after which the valve should be clamped face up on the table and the exhaust edges cut to the lines laid out.

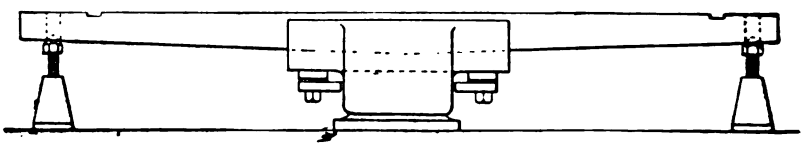


Fig. 43

Errors in Planer Work.—Errors in planer work may be due to any one or a combination of the following causes: Errors in setting the machine; errors due to the table being out of true; errors due to the cross rail not being true with the ways; errors due to the spring of the machine; errors due to improper clamping of the work to the table.

A planer should be set on a good foundation, preferably of brick or stone. The table should be removed and the bed leveled in both directions by using a level and straight edge on circular parallel pieces as shown in Fig. 47. Care should be taken that the supports of the bed rest fairly

Fig. 45

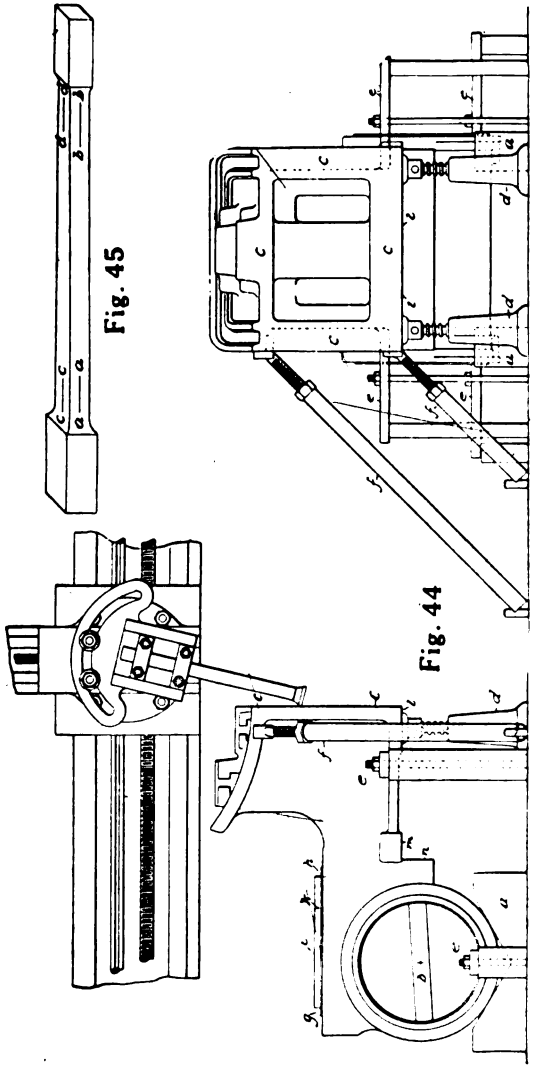


Fig. 44

on the foundation. Time spent in properly setting a planer is not thrown away, for if the planer is well set at the beginning it will remain true for a long time.

After a planer has been in use for some time it will be found that the table is no longer true, but will be sprung up in the center more or less. This springing of the table is due to the driving in of stop pins too hard and the careless dropping of work on the table. These causes tend to peen or stretch the metal in the top of the table, thus causing the table to spring up in the center. A table in this condition will bear on the ways at the ends only, and if the cut is long enough to cause the ends of the table to overrun the bed, the ends of the table will drop down and the work instead of being planed straight will be more or less rounding. Where such a condition exists the top of the table should have a light cut taken over it to remove the peened surface. This truing should be done by taking a number of light cuts, for if a cut heavy enough to cut the entire length of the table is taken, it will be found as the cut proceeds that the removal of the peened surface releases the tension in the top of the table and it will gradually go back to its original form. This will result in the portion planed first being concave instead of straight. Before attempting to true up the table the cross rail should be tested to see that it is parallel with the *ways*, as the cross rail should be adjusted to the ways, not the table.

The cross rail is raised and lowered by the two

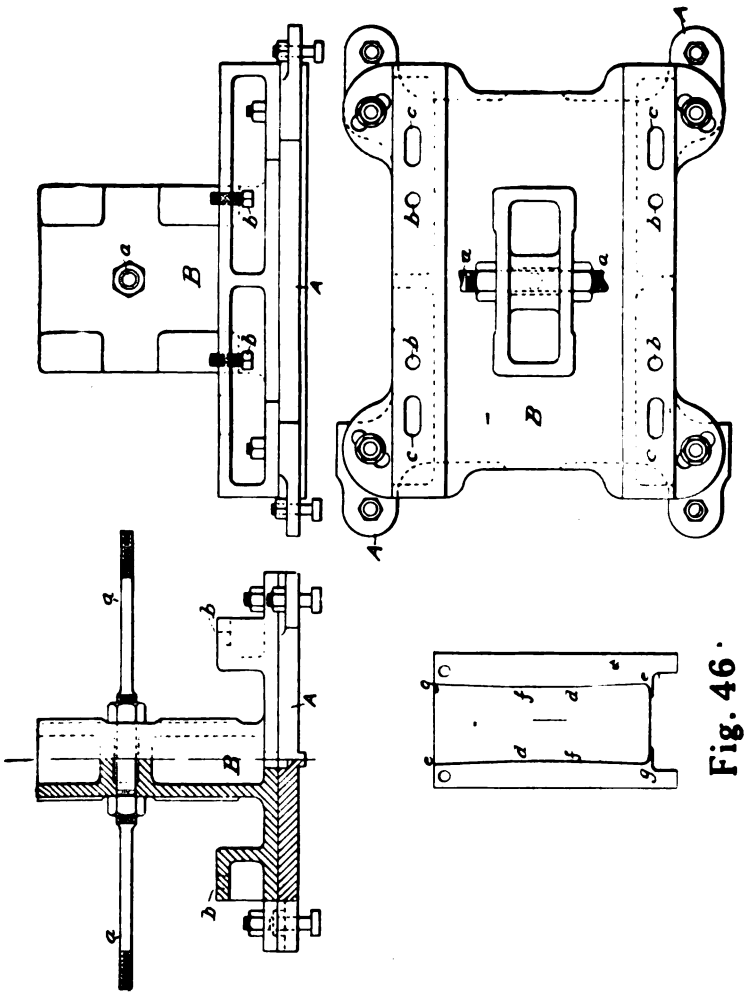


Fig. 46.

elevating screws in the housings. These screws are the same pitch, so that when the cross rail is moved each end will move the same amount, and if the cross rail is set parallel to the ways in one position it should be parallel to them in any other position. If the cross rail is not securely clamped to the housings while taking a cut, a strain will be thrown on the elevating screws and nuts and the cross rail will be thrown out of adjustment more or less. This will result in

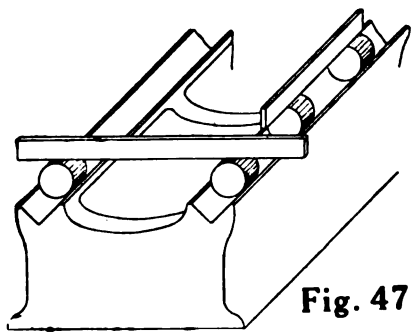


Fig. 47

work being planed thicker on one edge than the other. The alignment of the cross rail may best be tested by placing a truly cylindrical piece in one of the ways and adjusting a square nosed tool so that it will just pinch a piece of thin paper placed between the tool and the test piece. Then place the test piece in the other way and move the tool over it, when, if the cross rail is parallel to the ways, it should grip the paper with the same degree of tightness as before. If the cross rail is out of adjustment, it should be corrected by raising the low end by turning

that elevating screw the required amount and securing it in position. How this may be done will depend on the construction of the planer.

If the cross rail or planer head is loose, an error may be introduced the magnitude of which will depend on the amount of looseness existing. If a planer is used on a class of work where the head travels over a limited portion of the cross rail, the rail will become worn at that point and it may be difficult to produce parallel work. In such cases the only remedy is to determine the amount of the error and use packing of sufficient thickness between the work and the table to correct the error.

Probably the most frequent cause of error in planer work is the improper clamping of the work, causing it to be sprung more or less. As before stated, care should be used to see that the packing used to level the work on the table and the clamps is so placed that the work will not be sprung when the clamps are tightened. In clamping heavy work it is sometimes very difficult to determine whether it is equally supported at all points, because the work will twist and bend of its own weight, and may have considerable twist in it notwithstanding that it may appear to bed fairly on the table. Such work may be set in the following manner. Fig. 48 represents a casting which is to have the upper surface planed. It should be balanced upon two wedges *a* and *b*, one being placed at each end, the wedges being adjusted so that the casting is level. A line should be drawn across the

face of each wedge in line with the face of the casting. Four wedges, two of which are shown at *c* and *d*, are then placed on each side of the casting and shoved in until they just meet the casting, and a line is drawn across them in line with the edge of the casting. Wedge *c* is then driven in until it relieves wedge *a* of the weight of the casting, and a second line is drawn across the face of wedge *c*. It is then withdrawn and the wedge on the opposite side of the casting is

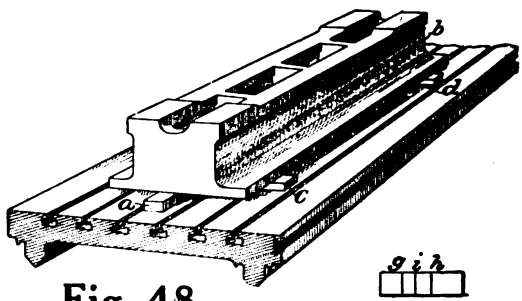


Fig. 48

driven in until wedge *a* is relieved, when a second line is drawn on the face of this wedge. The wedges at the other end are marked in the same manner and then the four side wedges are withdrawn, having upon their faces two lines *g* and *h*, as shown at the right of Fig. 48. Midway between these two lines a third line *i* is drawn and all four wedges are then driven in until line *i* is in line with the edge of the casting. This being done it may be assumed that the casting is equally supported at the four points. Long work which does not bed on the table should be

supported at several points so that the pressure of the cut will not spring it.

The removal of the surface metal from forgings and castings relieves the internal stresses, as was explained with reference to lathe work, and therefore the work will alter its shape as the machining proceeds. For this reason the work should be roughed out all over before any finishing cuts are taken when it is possible to do so. If very accurate work is to be done on work that is not to be finished all over, the clamps should be released and the work re-set before the finishing cut is taken.

Owing to the construction of the shaping machine, the errors due to the spring of the tool and work will be greater than is the case with the planer. This is due to the impossibility of fitting the ram without lost motion in the guides. Also, when the stroke is long, the ram will spring more than when it is close to the column. The table also has a tendency to sag down, as it has considerable overhang, and this tendency is increased by the pressure of the cut. The only way to overcome or lessen these defects is to keep the machine carefully adjusted so that all lost motion between the ram and slides is at a minimum and also that the table gibs are kept tight.

As was mentioned in the early part of this chapter, the planer and shaper tool heads are so constructed that the head may be swung around so that surfaces at any other angle than 90° to the table may be machined. The head is

graduated in degrees to facilitate the setting. Some planers are so graduated that the 0° is at the side and 90° at the top, while others have the 0° at the top and bottom and 90° at the sides. The difference in these markings must be taken into account when setting the head to get the correct angle, as will be shown by the following example.

Fig. 49 shows a piece of work that is to have a part of the top surface machined at an angle

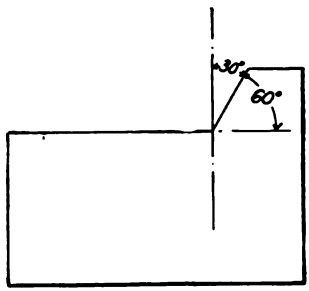


Fig. 49

of 30° from the vertical, or 60° from the horizontal line. If the head has the 0° at the top it will be swung to the right until the 60° mark on the head corrresponds to the line on the saddle, as $90 - 30 = 60$. If the 0° was at the side, corresponding to the line on the saddle when the head stands vertical, the head would be swung to the right until the 30° mark comes opposite the line on the saddle. If the 0° stands at the side all measurements of angles should be taken from a surface at right angles to the planer

table; if the 0° is at the top the angles should be measured from a surface parallel to the table.

In taking side or bevel cuts on the planer or shaper the tool block, *not the head*, must be swung to one side to prevent the tool from catching the work on the back stroke. *The top of the tool block should always be moved away from the plane of the surface to be planed, and the tool should always be fed down.*

All planer and shaper tools forged from bar steel are very similar in shape to the forged tools used in the lathe, with the one exception that in the case of planer and shaper tools the bottom clearance may be less and may also be constant, because the tool feeds to its cut after having left the work surface at the end of the stroke. A planer or shaper tool should not be given more than 10° of clearance, and in the case of broad flat nosed tools for finishing cuts it need not be more than 5°. The principle of pulling rather than pushing the tool to its cut can be more readily carried out in planer than in lathe tools, because the spring of the tool and the tool head, only, need to be considered, the position of the tool with relation to the work being otherwise immaterial. Fig. 50 shows two tools, *W* being the work, and *a* the fulcrum about which the tools will spring under the pressure of the cut. The arrows *b* denote the direction in which the point of the tool will spring. It will be seen that the tool at the left of the figure will dip deeper into the work as the pressure of the cut increases, as it will from any

increase of the depth of the cut in roughing out the work, or from any seams or hard places in the metal during the finishing cut. In the case of the tool at the right, the spring of the tool tends to raise it away from the work. This form of tool, while being rather difficult to forge, makes a fine finishing tool for wrought iron and steel. In any event the point of the tool should be kept as close to the back of the tool shank as possible. For taking finishing cuts on cast iron a very broad nosed tool should be used with just clearance enough to allow it to cut. The

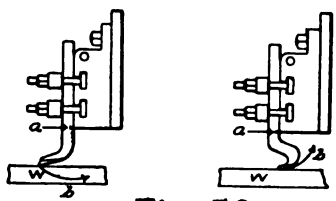


Fig. 50

corners should be eased off slightly with an oil stone, and the feed should be slightly less than the width of the tool.

The cutting speed of planer and shaper tools is governed by the same considerations as were given for lathe tools. With the ordinary planer there is no provision made for varying the cutting speed after the machine has been set up, hence a suitable cutting speed is selected for the work each particular planer is expected to do. In order to adapt the planer for the cutting of [illegible]d metals and heavy cuts, it is generally set

up to run at a speed of from 15 to 25 feet per minute. This speed is much below that which would be suitable for brass and other soft metals, so that modern installations of planers now make provision for varying the speed of the countershaft, so that the table speed may be easily changed to accommodate the varying conditions of material and depth of cut.

Shapers are provided with stepped driving cones and back gears, thus giving a wide range of cutting speeds. If this provision were not made, it would require the same length of time to machine a short piece of work that it would take to machine a long one.

The use of "high speed" tool steels has been extended to the planer and shaper, and where these machines have been speeded up correspondingly, the output has been greatly increased, in some cases more than doubled.

CHAPTER XXI.

MACHINE WORK.—SLOTTING MACHINE WORK.

The slotting machine, or slotter as it is commonly called, is a modification of the shaper, and is a very important tool in railway shops.

Fig. 1 shows a modern type of slotter, and it will be seen that the cutting tools are carried on a ram *C*, that has a vertical movement, the work table *G* occupying a horizontal position. The cone spindle *F* has a pinion which drives the large spur wheel *H* upon a horizontal shaft. This spur wheel is connected to the shaft by a "quick return motion," the housing of which is shown at *I*. Upon the inside of this spur wheel is a cam groove *f* for operating the automatic feed motions. At the opposite end of the shaft from gear *H* is fastened the crank disc *J*, which has a crank pin movably mounted in a radial slot in its face. This crank pin may be rigidly fastened in any desired position, thus regulating the stroke of the ram *C*. The crank pin is connected to the ram by a connecting rod and wrist pin. One end of the wrist pin is shown at *K*, and it is adjustable in a slot *g* in the ram, thus allowing the position of the ram to be adjusted with reference to the work table. This adjustment is made by operating the handle shown at *L*. The cutting tools are carried in the clamps *h*, *h*, *h*, at the lower end of the ram.

The ram is counter-balanced by the weight *M*, so that the ram is always held up and there is no jump when the tool meets the work.

The work is secured to the circular table *G*, this table being capable of being revolved about

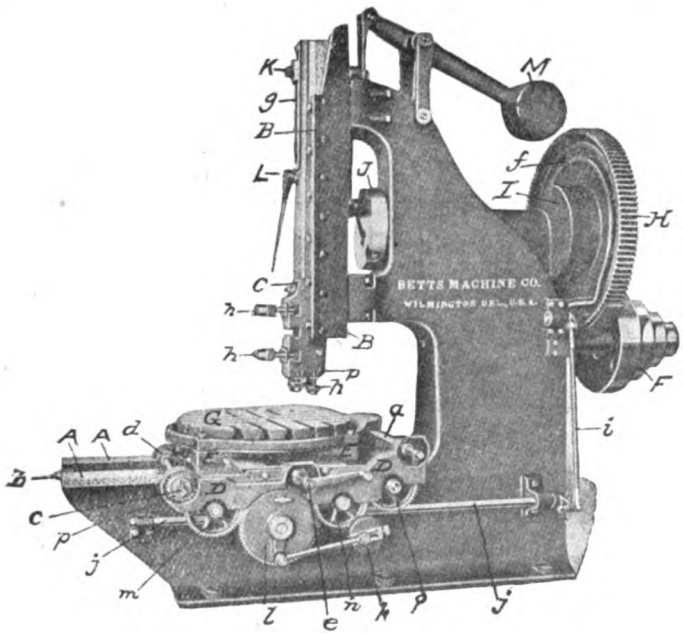


Fig. 1

its axis to feed the work to the cut. This table is carried upon a compound slide having two horizontal motions, one at a right angle to the other. The lower slide *D* is operated by the rod *b* running through the center of the machine, this rod being operated by the worm wheel *d*

on shaft *c*. The upper slide *E* is operated by feed screw *e*. Feed rod *a* has a worm that meshes with teeth cut on the periphery of the circular table, thus rotating the latter. These three feed motions may be operated by hand, or automatically through the medium of the rod *i*, shaft *j*, adjustable crank *k*, and the gears *l*, *m*, *n*, *o* and *p*. Gear *p* slips on to the various feed rods, and in the position shown in the figure

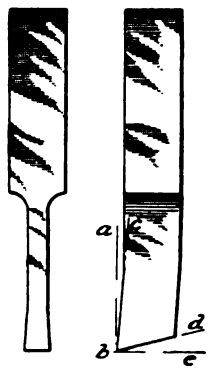


Fig. 2

the feed motion for the lower slide *D* would be operated.

The cutting tools are carried in one of these ways: first, bolted direct to the face of the ram, in which case they stand vertically; second, in a box, or apron *p*, secured to the lower end of the ram, in which case the tool will stand horizontally; third, held in a tool bar, in which case the tool may stand horizontally or vertically, depending on the construction of the tool bar.

Fig. 2 shows a form of tool used when the tool is carried in the first described method. The cutting edge is formed at the end of the bar, and the shank of the tool is generally made square so that the tool may be turned in any one of four directions. In this tool the angle *a*, *b*, *c* is the angle of clearance, and the angle *d*, *b*, *e* is the top front rake. This form of tool is not used to any great extent except for cutting key ways or slots which are too narrow to admit of a tool bar. If the slots to be cut are long, it will require a long slender blade to reach through the work and the tool will spring considerable, so that only very light cuts can be taken.

Fig. 3 shows a tool holding bar for the slotter, designed and patented by Mr. William T. Slider, of Indianapolis, Ind. The construction is clearly shown by the figure. The upper part, or sleeve *a*, is clamped to the ram. Annular grooves *b*, *b* are cut in this sleeve at intervals, and by means of pins *c*, *c* which pass through the clamps *d*, *d*, the sleeve can be locked in place, insuring it against the possibility of being forced upward under the pressure of a heavy cut. The several grooves in the sleeve permit it to be closely adjusted to suit the work. By loosening the clamping bolts the sleeve may be turned about its own axis. The clamping collar *e* at the top prevents the sleeve from dropping in case the clamps are loosened and the pins removed at the same time. The upper part of the tool post *f* has a forked lower end, the upper portion being turned down as a stem which passes

through the sleeve *a*, and is held in place by the nut and washer *g* at the upper end. The joint between the post *f* and the sleeve *a* at *h* is tapered as shown, so that when the nut *g* at the top is drawn up, there will be no lost motion be-

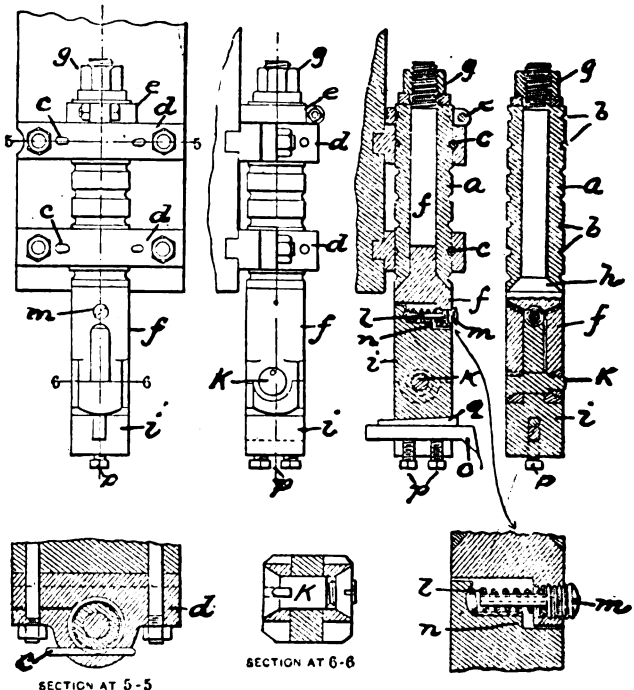


Fig. 3

tween them. When the nut *g* is loose the post *f* may be turned to any position. These two parts have marks upon them so that they may be easily brought to any predetermined position.

One of the marks on the sleeve *a* extends up to the clamping bracket upon which there is a corresponding mark, and when these register the work on the table can be squared up by the bar, as a portion of the post *f* at its lower end is squared for this purpose.

The lower part of the post *i* is pivoted to the forked end by the pin *k*. This allows the lower part to swing backward slightly on the return stroke, the spring *l* forcing it into place as soon as the tool leaves the work. The tension of the spring may be adjusted by the screw *m*, and if desired, the post may be made rigid by turning screw *m* in until it meets the shoulder at *n* on piece *i*. The pivot *k*, upon which the lower part swings, is placed to one side of the center so that the faces of the two parts which come in contact when the tool is cutting will have ample area to resist the pressure of the cut. The cutting tools *o* are held in the slot by the two set screws *p* and may also be held by a tapered key *q*, if desired.

The cutting tools for use in this bar are similar to ordinary planer and shaper tools and should have the same amount of clearance.

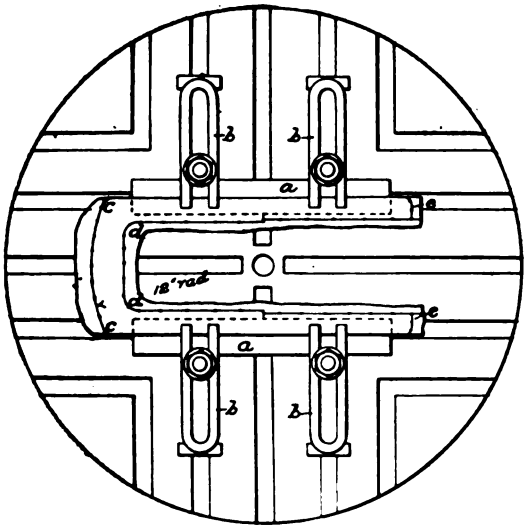
In operating a slotter care must be taken that the tools or ram do not strike the table. The height of the ram should be so adjusted that the end of the tool will pass by the lower edge of the work, but not touch the table. To set the ram it should be lowered so that the tool bar, or tool if it is of the solid type, rests on a piece of metal of suitable thickness on the

table. With the clamps loose, the machine should be turned by hand until the crank pin is at the lowest point of the stroke, after which bolt *K*, Fig. 1, is tightened. If any change in the length of the stroke is made, the position of the ram will require re-adjustment.

Owing to the relative position of the ram and work table, almost all slotter work must be laid out with lines, as the construction of the machine makes it impossible to set work true by using the surface gauge, or calipers, as may be done in the case of the planer and shaper. The work is secured to the table by clamps as was described with reference to planer work, and the same care must be used in adjusting the clamps so as not to spring the work. In very few cases can the work be secured directly to the table, it being necessary to support it on parallel strips in order to enable the tool to pass beyond the lower edge of the work.

In railway shops the following work is generally assigned to the slotter, and a brief description of the setting up of this work will be given.

1. Machining the inside surfaces of rod straps.
2. Machining the brass and cellar fits of driving boxes and cellar fits of engine truck boxes.
3. Machining the edges of locomotive frames.
4. Squaring the ends of connecting and parallel rods and cutting the key ways in same.
5. Cutting key ways in driving wheels.
6. Machining the edges of driving box brasses,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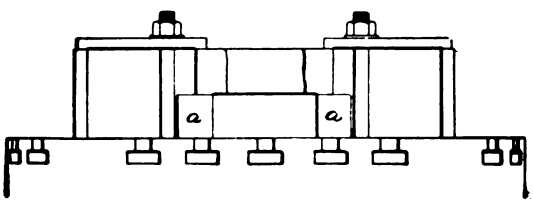

a
a

and sometimes used for machining the circular portion of the brass.

8. Used for machining any other surfaces for which the peculiar construction of the slotter makes it particularly adaptable.

Fig. 4 shows a rod strap as it should be laid out to have the fit for the brass and rod machined, also to have the ends trued up. The strap is placed on two parallel pieces *a*, *a*, these pieces being so placed that they will come inside of the scribed lines as shown. The strap is secured by four clamps *b*, *b*, *b*, *b*. After securing the strap in this manner a pointer is clamped in the tool bar and the work brought under it so that the pointer just comes to the scribed line. The setting of the work is then tested by moving the work table past the pointer and noting if the pointer follows the scribed line. If it does not, the work table should be revolved until the pointer will follow the line. The table should be then clamped in this position and the two right angled feeds will allow the lines to be followed. The inside corners at *d*, *d* must be finished with a tool ground to the correct radius. In the strap shown, the butt end is finished to an arc of a circle having a 12-inch radius. In this case the strap must be so set that the center of this arc will coincide with the axis of rotation of the table. This may best be done by using a suitable mandrel in the center hole of the table and setting line *c*, *c* true with the mandrel by using hermaphrodite calipers as shown with reference to setting driving boxes in Fig. 5. Where

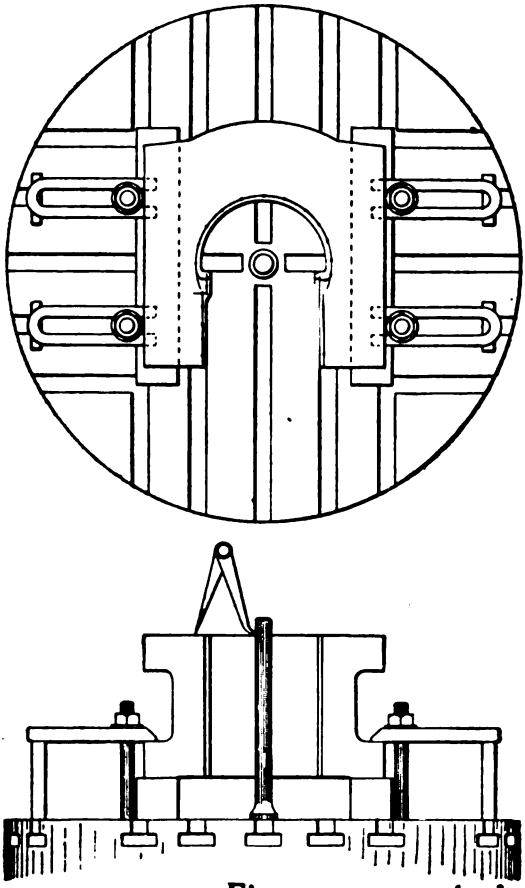


Fig. 5

there are a number of similar straps to be slotted they should be placed one on top of the other, the top one only being laid out.

Fig. 5 shows a driving box set to have the circular fit *a*, *a*, *a* for the brass, and the fits *b*, *b* for the cellar machined. The box *A* is placed on the two parallel pieces *c*, *c*, and secured with the four clamps *d*, *d*, *d*, *d*. The center from which the line *a*, *a*, *a* was scribed must be set exactly over the axis of the table by using the mandrel *e* in the center hole in the table. This mandrel should be some even number of inches in diameter and the hermaphrodite calipers set to the radius of the circle *a*, *a*, *a*, less one-half the diameter of the mandrel. The corners at *a*, *a* should be finished with a formed tool. After finishing the brass fit, the cellar fits should be machined, setting the table to the lines *f*, *f*, as was described with reference to the rod strap.

Fig. 6 shows a main frame set to have the various fits for the front frame machined. The frame *A* is placed on the parallel pieces *a*, *b*, *c*, *d* and *e* and is secured to the table by the clamps *f*, *g*, *h*, *i*, *j* and *k*. The rear end of the frame is supported by the two horses *B* and *C*. On top of these horses are placed the two rollers *l* and *m*, and on top of these the single roller *n* supports the frame. The horses must be carefully leveled up to such a height that the roller *n* will be in line with the top of the parallel pieces. This system of rollers will allow the movement of the frame in the direction of the longitudinal and lateral table feeds. After the inside sur-

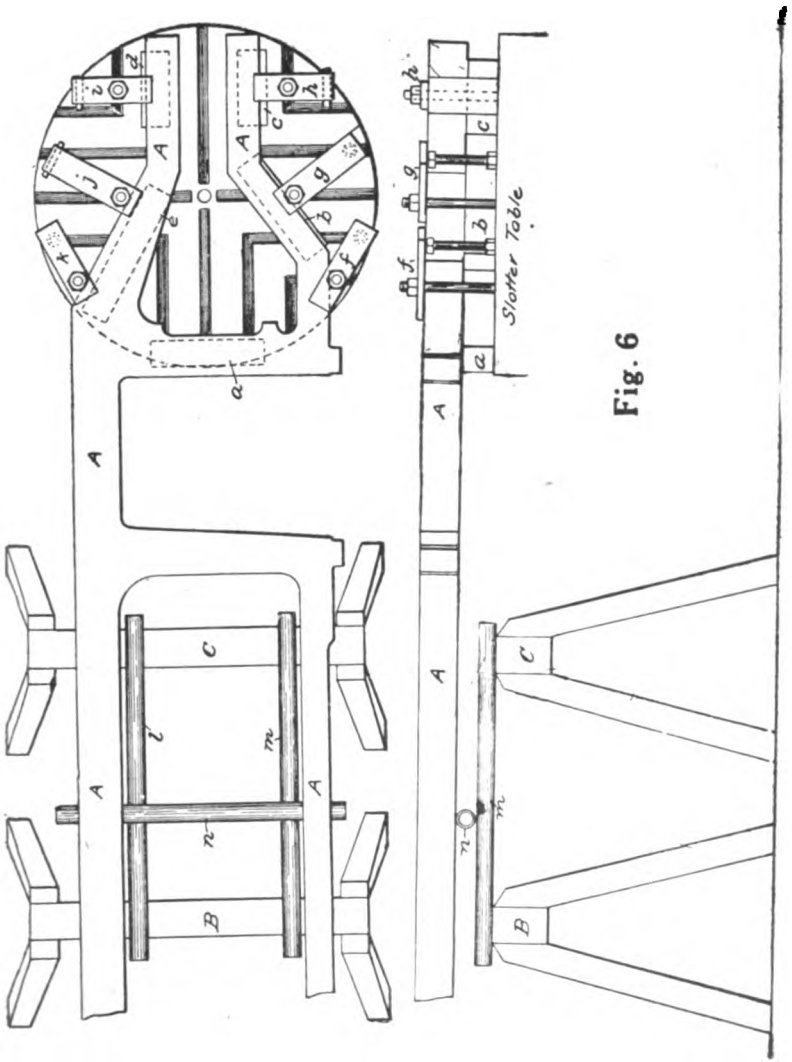


Fig. 6

faces are machined the clamps must be changed to enable the outside surfaces to be reached. Care must be taken to get the horses the correct height and level with the table, so that the frame will not be sprung by the clamps.

Shops where much frame work is done are generally provided with a special frame slotter. These machines are of the traveling head type,

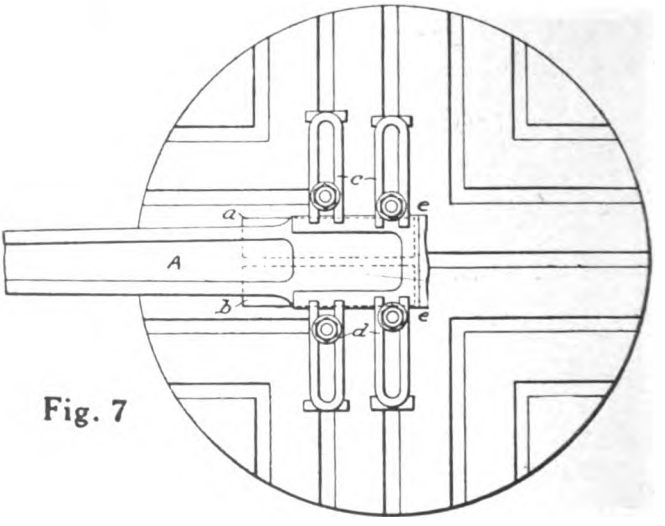


Fig. 7

the work remaining stationary while the tool is given the feed motions. They have a stationary work table long enough to take the largest frame to be machined, the rams, of which there are two or more, being supported by housings similar in form to those of a planer. These housings are movable along the bed, and the rams, being supported by a cross rail between

the housings, are movable across the table. These slotters have no circular movement, the two feeds being at right angles to each other.

Fig. 7 shows a connecting rod set up to have the end squared. The stub end of the rod *A* is supported on the parallel strips *a* and *b*, and secured to the table by the clamps *c* and *d*. The rod is to be cut off to the line *e*, *e*, and the table must be so adjusted that the tool will follow this line. The overhanging end of the rod must be supported either by horses, as was

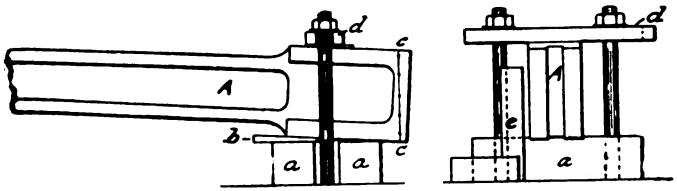


Fig. 8

described with reference to Fig. 6, or by holding it up by means of a chain block from the roof trusses, whichever may be most convenient.

Fig. 8 shows a connecting rod set up to have the key way cut. The rod *A* is supported on the parallel strips *a*, *a*, and is adjusted with the wedge *b* so that the line *c*, *c*, which indicates the taper of the key way, will be square with the table. The stub end of the rod must be set perfectly square with the table by using a square as at *e*. For cutting key ways a tool similar to that shown in Fig. 9 should be used. The shank *A* fits the slot in the tool post, and the body *B*

should be ground to the exact width of the key way to be cut. The cutting edge is along the line *C*, *D*.

Fig. 10 shows a jig for holding driving box brasses while machining the lug fits at *a* and *b*. The jig consists of a V block *A*, which is bolted to the slotter table as shown. The brass is clamped in a vertical position by means of the clamp *B* and $\frac{7}{8}$-inch bolts *c* and *d*. Two lugs *e* and *f*, 2 inches high and 1 inch thick, hold the brass above the table, thus providing clearance for the tool at the bottom of the stroke. Brasses

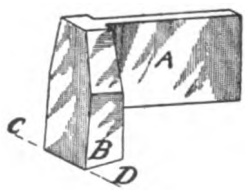


Fig. 9

can be machined in this manner on the slotter much quicker than it can be done on the planer, as the table feeds of the slotter enable the brass to be adjusted to the lines more readily than can be done on the planer, and a more rapid cutting speed can generally be obtained.

In some shops a somewhat similar device is used for holding a brass to the slotter table for machining the circular fit of the brass. With a properly designed mandrel, or jig, this work can be done on the slotter quicker than it can be done in a lathe.

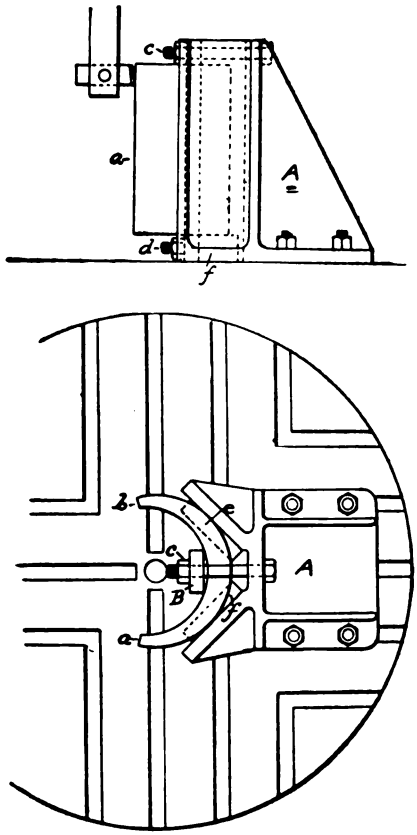


Fig. 10

Fig. 11 shows the hub of a driving wheel laid out to have the key way cut. This key way is generally cut on the side of the axle bore next to the crank pin, and on a line joining the centers of the axle and crank pin bores. This being

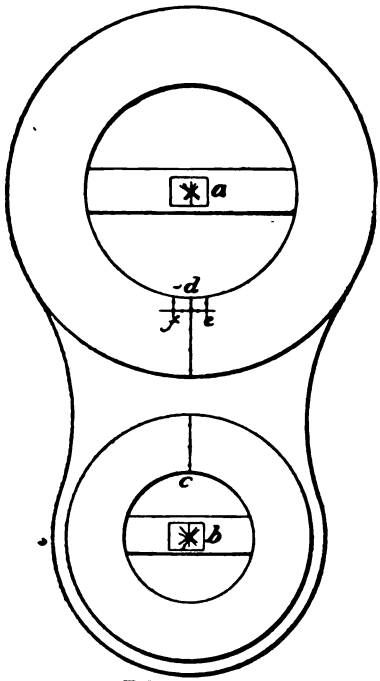


Fig. 11

the case it is necessary to locate the line *c*, *d*, joining these two centers. This line may be located by finding the centers of the axle and crank pin bores, as at *a* and *b*, and with a straight

edge set to these centers scribing the line *c, d* on the hub face. The key way is then laid out central with the line *c, d,* as shown in the figure.

A better method of locating line *c, d* is shown in Fig. 12. In this case two center squares are

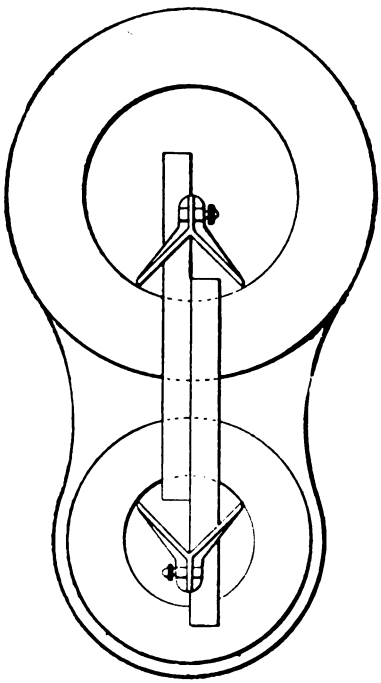


Fig. 12

used as shown. This method is quicker and generally more accurate than the first. In case the crank pin is in the wheel the line *c, d* may be located as follows (see Fig. 13). A center square

is applied to the axle bore as shown at *A*, and a line *a*, *b* scribed along the edge of the square. The square is then placed in the position *B*, shown by the dotted lines, and the line *e*, *f* scribed. From the points where the lines *a*, *b*

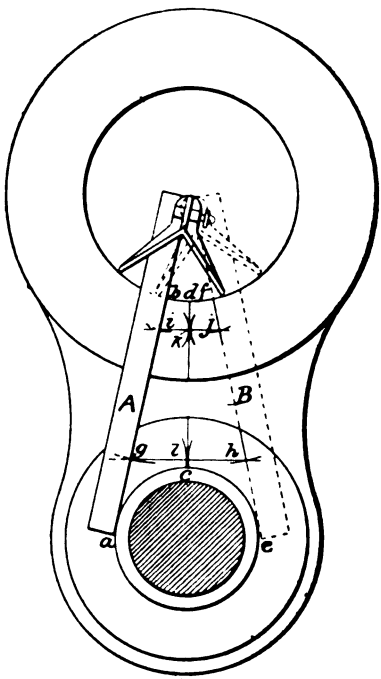


Fig. 13

and *e*, *f* intersect the axle bore, with a pair of hermaphrodite calipers set to any convenient distance, arcs are scribed intersecting the lines *a*, *b* and *e*, *f* at *g* and *h*. Setting the calipers to

a less distance, in a similar manner, the arcs *i* and *j* are scribed. The points of intersection of these arcs with lines *a*, *b* and *e*, *f* are joined by lines *g*, *h* and *i*, *j*, and these lines bisected at *k* and *l*. The line *c*, *d* is then drawn through points *k* and *l*, and if the work has been carefully done, it will join the centers of the axle and crank pin bores.

To cut the key way the wheel is secured to the slotter table and the table adjusted until the tool will follow the line *c*, *d*. The key way is then cut, being careful to see that it is cut central with line *c*, *d*.

Errors in slotting machine work will be due generally to errors in setting the work, but in some cases there will be an error due to the spring of the ram. To overcome this, the ram slides must be kept closely adjusted. Sometimes a slotter will be found in which the ram does not travel exactly at a right angle to the top of the work table. Where such is found to be the case, the error may be corrected by the proper shiming up of the work.

The same considerations govern the cutting speeds and rate of feed as have been previously discussed.

CHAPTER XXII.

MACHINE WORK—MILLING MACHINE WORK.

Until within the last few years the only type of milling machine found in railway shops was the universal machine, and its use was confined almost entirely to tool room work.

While the milling machine, as originally developed, was intended for the production of duplicate work of intricate outline, it is gradually becoming recognized that the process of milling may be economically applied to a great variety of work usually performed in the shaper, planer and slotter. In the following pages some examples of this class of work will be given.

To obtain the maximum benefit from the milling machine, the making of the tools and fixtures calls for a very high order of skill, and the work must be handled in as large quantities as possible. The adjustment of the machine, or "setting up," requires the services of a skilled machinist, but after it has once been adjusted, the actual placing of the work into the machine, taking the cut, and removing the work may be done by a less skillful hand. However, when the milling machine is used to take the place of a shaper, planer or slotter on single jobs, the employment of a competent machinist is absolutely necessary, since in such cases the same degree of skill is necessary for the opera-

tion of the milling machine as is necessary for the operation of the machine tool whose place is being taken by the milling machine.

As will be shown later, the milling cutters are so formed as to generate the full profile of

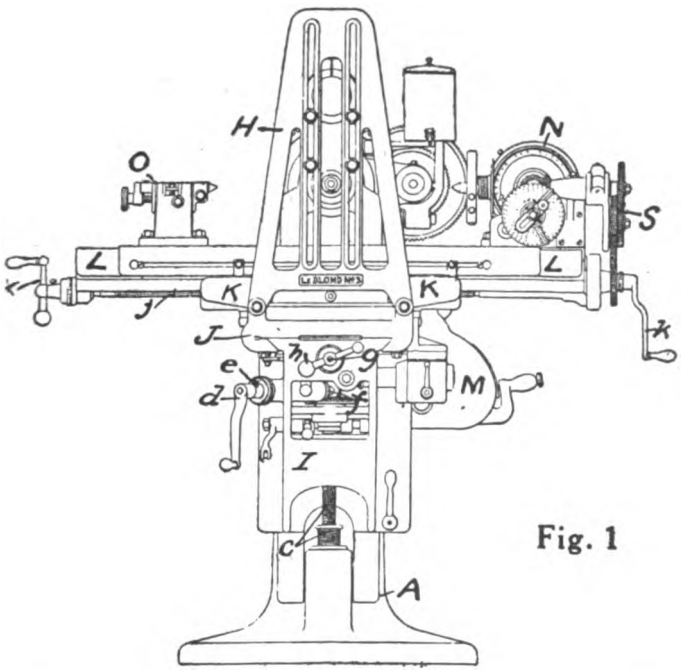


Fig. 1

the work surface as the cutter advances over the work, hence the accuracy of the work will depend on the accuracy of the cutter, and the accuracy of the measurements taken in setting the work. With the planer, shaper and slotter, the accuracy of the work depends almost en-

tirely on the personal skill of the machinist.

Milling machines are built in a variety of forms, the more common ones being the plain and universal machines of the column form, the vertical spindle machines, and the various forms of "planer type" machines.

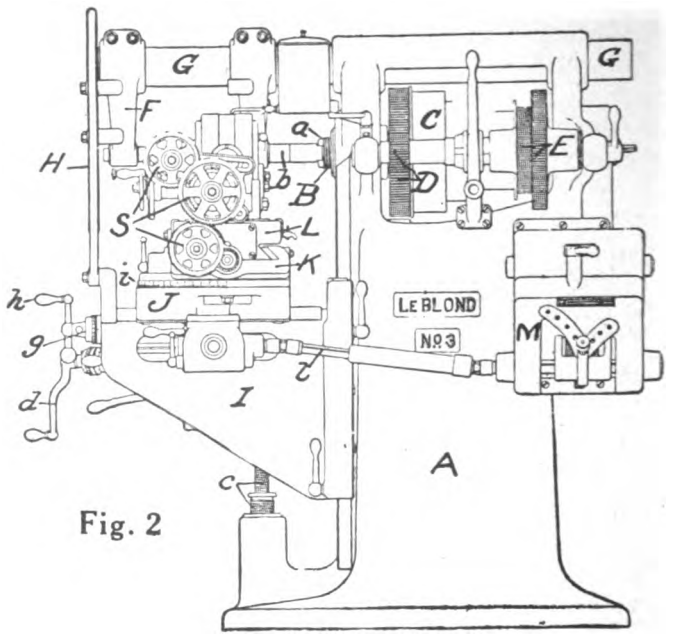


Fig. 2

Figs. 1 and 2 show the usual type of universal machine. The frame *A* supports the bearings for the spindle *B* which is driven by the cone *C* from the countershaft. The spindle is "back geared" in the same manner as the lathe, the back gears being shown at *D* and *E*.

The spindle is hollow, and the end at *a* is bored taper to receive the shank of the cutter, or an arbor *b* upon which the cutter is mounted. The outer end of this arbor is supported in a bearing in the arm *F*, which arm is adjustable upon the bar *G*, which is parallel to the axis of the spindle. This arm is further supported by clamping it to the frame, or support *H* affixed to the table. It is evident that the frame *H* cannot be used if the vertical table feed is to be operated. The knee *I* is fastened to the vertical face of the frame in much the same

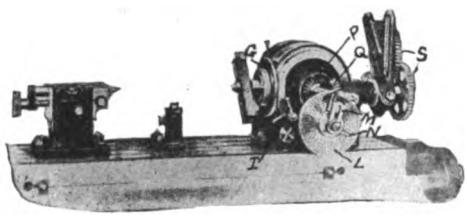


Fig. 3

manner that the cross slide is secured to the shaper frame. This knee can be raised and lowered by turning the elevating screw *c*, which is operated from the front of the machine by the handle *d*, shaft *e*, and the bevel gears at *f*. The top of the knee is finished at a right angle to the surface of the slide on the frame, and is, therefore, parallel with the axis of the spindle. The clamp bed *J* is carried on the top of the knee, and can be moved along it in a straight line parallel with the spindle axis. This move-

ment is secured by means of the cross feed screw *g* and handle *h*. The clamp bed carries the saddle *K*, which is pivoted to it, and which can be rotated through an angle of about 45°. The base of the saddle is graduated in degrees, as shown at *i*, for convenience in setting. The 0° on the saddle corresponds with the line on the clamp bed when the axis of the table *L* stands at a right angle to the axis of the spindle. The upper part of the saddle is formed into ways which carry the table *L*. The movement of the table, which is parallel to the top surface of the knee, is controlled by the feed screw *j* and handles *k*. The various feed motions may be operated automatically, the power being conveyed through a nest of change gears at *M* and shaft *l*. The feed screws have graduated collars reading to $\frac{1}{1000}$ of an inch, so that adjustments may be easily and accurately made. These collars are locked in any position by suitable thumb screws.

Universal milling machines are always furnished with a variety of attachments, such as a vise, raising blocks, chucks, face plates and universal dividing head. The most important of these attachments is the universal dividing head and tail center, which are shown at *N* and *O*, Fig. 1, the two comprising what is commonly called a pair of index centers. These centers are shown in Fig. 3, and two sectional views through the dividing head are shown in Fig. 4.

The head and tail centers are bolted to the table, being held in line by suitable tongues on

the bottom, which fit in the *T* slots in the table. Referring to Fig. 4, the spindle *A* rotates in bearings in the head *B*, and on it at *C* is affixed a worm wheel which engages with the worm *D* on worm shaft *E*. The spindle is hollow, and is bored out taper for the reception of the center *F*, and the nose is threaded to take the chuck and face plates. Attached directly to the spindle is an index plate *G*, which is held in any desired position by the pin *H*, operated by the

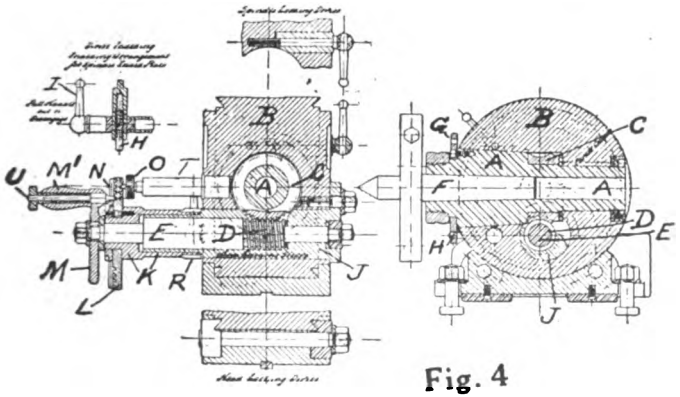


Fig. 4

handle *I*. This plate generally has 24 holes, and is used for miscellaneous dividing when the number of divisions is small. The worm shaft turns in an eccentric sleeve, offering an effective way of taking up the wear between the worm and worm wheel, and also for disengaging the worm from the wheel for direct indexing by means of plate *G*.

The worm shaft *E* carries on its outer end the sleeve *K*, which is free to rotate about the

shaft. The inner end of this sleeve has gear teeth cut upon it at R, which teeth mesh with teeth cut upon the periphery of the bevel gear P (see Fig. 3). This bevel gear is mounted upon shaft T, Fig. 4. The dividing plate L is held to the sleeve K and rotates with it. The crank M is secured to the end of the worm shaft, and carries the handle M^1 which is adjustable radially in the crank. A small pin U passes through the handle and engages the holes in

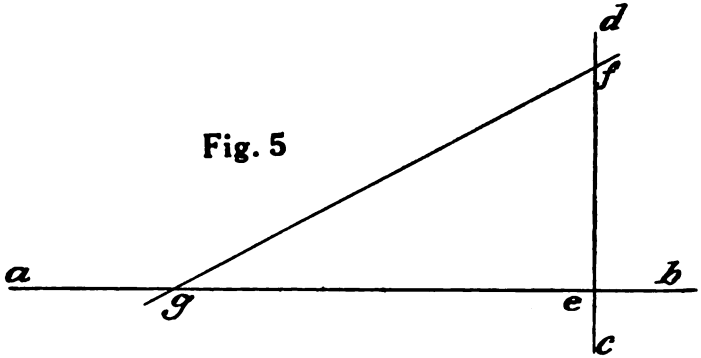


Fig. 5

any of the circles in plate L. Another pin O is attached to the head B, which pin may be engaged with holes in the back of the dividing plate, thus preventing the plate from rotating. In order to keep the dividing plates of a convenient diameter, several plates are necessary to get the range of divisions generally provided. A sector N, mounted loosely on the worm shaft between the handle and the dividing plate, serves to assist in counting the number of spaces between the holes, and can be adjusted

to include any desired number of spaces between the radial arms.

As all dividing heads are so constructed that it requires forty turns of the handle *M* to make one turn of the spindle, the following rule will determine the spacing for any required division.

Write 40 as the numerator, and the required number of divisions as the denominator of a fraction. Reduce this fraction to a mixed number or another fraction, as the case may be, the fraction having a denominator corresponding to the number of holes in any circle available.

Thus, suppose it is required to cut 27 teeth in a gear. $\frac{40}{27} = 1\frac{13}{27}$, hence it will require one complete revolution of the handle plus $\frac{13}{27}$ of a revolution. The sector should be set to include 13 spaces (14 holes) on the 27-hole circle. Suppose it is required to cut 100 teeth. $\frac{40}{100} = \frac{20}{50} = \frac{2}{5}$. This ratio will not be changed if both numerator and denominator are multiplied or divided by the same number. As no circle is provided with 5 holes, it will be necessary to find a circle having a number of holes exactly divisible by 5. Suppose a 20-hole circle is provided: $20 \div 5 = 4$, and $\frac{2}{5} \times \frac{4}{4} = \frac{8}{20}$; therefore, 8 divisions (or 9 holes) on the 20-hole circle will divide the gear into 100 divisions.

The majority of machines are provided with index plates having the following number of holes: 15, 16, 17, 18, 19, 20, 21, 23, 27, 29, 31, 33, 37, 39, 41, 43, 47, and 49, which will provide for all divisions up to 50, and all even divisions up to 100. Some machines are provided with

plates that will divide all divisions up to 360, and all are generally provided with a table showing the correct indexing, as follows:

No. of Teeth.	Index Circle.	No. of Turns of Index.	No. of Teeth.	Index Circle.	No. of Turns of Index.
2	Any	20	80	20	18
3	39	13 13/39	82	41	11
4	Any	10	84	21	10
5	Any	8	85	17	9
6	39	6 26/39	86	43	23
7	49	5 28/49	88	33	15
8	Any	5	90	27	12
9	27	4 12/27	92	23	10
10	Any	4	94	47	20
11	33	3 21/33	95	19	8
12	39	3 13/39	98	49	20
13	39	3 3/39	100	20	8
14	49	2 15/49	104	39	15
15	39	2 25/39	108	27	10
16	20	2 10/20	110	33	12
17	17	2 6/17	115	23	8
18	27	2 9/27	116	29	10
19	19	2 7/19	120	39	13
20	Any	2	124	31	10
21	21	1 14/21	128	16	5
22	33	1 11/33	130	39	12
23	23	1 15/23	132	33	10
24	39	1 15/39	135	27	8
25	20	1 12/20	136	17	5
26	39	1 13/39	140	49	14
27	27	1 12/27	144	18	5
28	49	1 21/49	145	29	8
29	29	1 11/29	148	37	10
30	39	1 12/39	150	15	4
31	31	1 11/31	152	19	5
32	20	1 8/20	155	31	8
33	33	1 7/33	156	39	10
34	17	1 7/17	160	20	5
35	49	1 7/49	164	41	10
36	27	1 9/27	165	33	8
37	37	1 7/37	168	21	5
38	19	1 1/19	170	17	4
39	39	1 3/39	172	43	10
40	Any	1	180	27	6
41	41	1 1/41	184	23	5
42	21	1 7/21	185	37	8
43	43	1 1/43	188	47	10
44	33	1 3/33	190	19	4
45	27	1 3/27	195	39	8
46	23	1 1/23	196	49	10
47	47	1 1/47	200	20	4
48	18	1 3/18	205	41	8
49	49	1 1/49	210	21	4
50	20	1 1/20	215	43	8
52	39	1 1/39	216	27	5
54	27	1 1/27	220	33	6

No. of Teeth.	Index Circle.	No. of Turns of Index.	No. of Teeth.	Index Circle.	No. of Turns of Index.
55	33	$\frac{24}{33}$	230	23	$\frac{4}{23}$
56	49	$\frac{36}{49}$	232	29	$\frac{5}{29}$
58	29	$\frac{22}{29}$	235	47	$\frac{8}{47}$
60	39	$\frac{26}{39}$	240	18	$\frac{3}{18}$
62	31	$\frac{22}{31}$	245	49	$\frac{8}{49}$
64	16	$\frac{12}{16}$	248	31	$\frac{5}{31}$
65	39	$\frac{24}{39}$	260	39	$\frac{6}{39}$
66	33	$\frac{24}{33}$	264	33	$\frac{5}{33}$
68	17	$\frac{12}{17}$	270	27	$\frac{4}{27}$
70	49	$\frac{35}{49}$	280	49	$\frac{7}{49}$
72	27	$\frac{18}{27}$	290	29	$\frac{4}{29}$
74	37	$\frac{24}{37}$	296	37	$\frac{4}{37}$
75	15	$\frac{8}{15}$	300	15	$\frac{2}{15}$
76	19	$\frac{12}{19}$	310	31	$\frac{4}{31}$
78	39	$\frac{24}{39}$	312	39	$\frac{5}{39}$

It will sometimes be required to make divisions not provided for by the regular plates and ordinary method of indexing. In such cases the required division may be made by what is known as "compound indexing," which consists of indexing forward on the front side of the plate in the usual manner, and then indexing either forward or backward, as the case may be, in a different circle of holes from the back of the plate. Machines which are equipped for this compound indexing generally have a table of such movements. Where such a table is not at hand the correct movements may be calculated in the following manner:

The number of divisions required should be factored to the lowest terms. Then choose an index plate and take two circles of holes for trial. Take the difference in the number of holes in the two selected circles and factor this difference. Draw a line under the factors. Next, factor the number of turns the index crank makes for one turn of the spindle, writing the factors below the horizon-

tal line. Next, factor the number of holes in the two circles chosen, placing these factors below the horizontal line. Now cancel equal factors above and below the line, and if ALL *the factors above the line cancel, it will be possible to make the required division with the index circles chosen, and the number of holes to be indexed* FORWARD *on one circle, and* BACKWARD *on the other circle, will be the product of the uncancelled factors below the line. If all the factors above the line do not cancel out, the division cannot be made, and two other circles must be chosen.*

It is evident that the factors of the number of holes in the circles chosen, and the factors of the number of worm turns per revolution of the spindle, must contain the factors of the division required and the factors of the difference between the number of holes in the chosen circles. If the division can be made, a plus sign should be written before one of the moves, and a minus sign before the other, to signify that they are to be made in opposite directions.

Suppose for example that it is required to obtain 77 divisions with a machine equipped with the usual index plates, the ratio between the turns of the worm and spindle being 40 to 1.

Choose two circles for trial, say those having 49 and 33 holes. By the rule given we would have

$$\begin{aligned} & 77 = 7 \times 11 \\ 49 - 33 = & \ 16 = 2 \times 2 \times 2 \times 2 \\ \hline & 40 = 2 \times 2 \times 2 \times 5 \\ & 49 = 7 \times 7 \\ & 33 = 3 \times 11 \end{aligned}$$

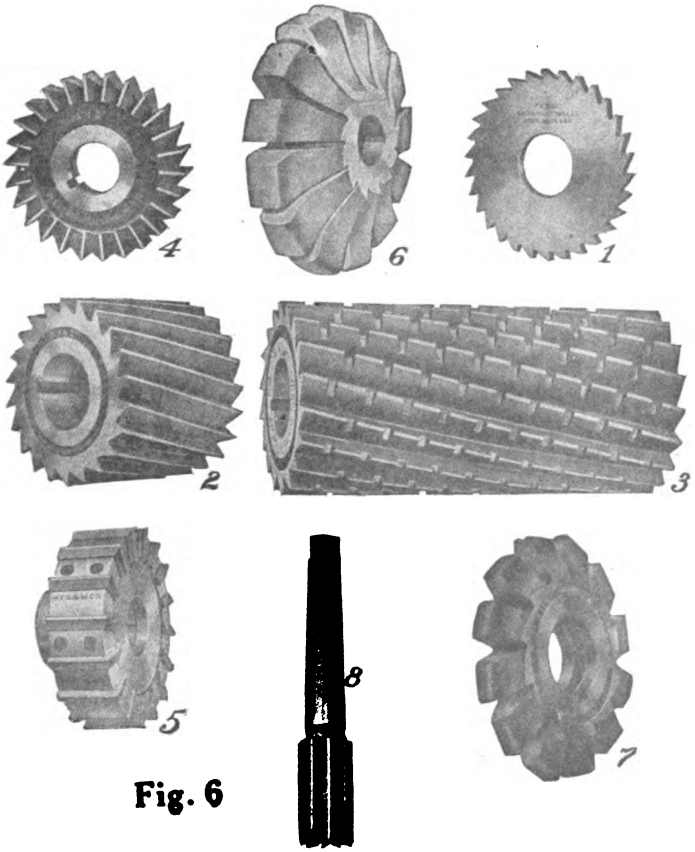


Fig. 6

As the factor 2 above the line does not cancel, the division can not be made with the circles selected.

Take for another trial the circles containing 33 and 21 holes.

$$\begin{array}{rl} & 77 = 7 \times 11 \\ 33 - 21 = & 12 = 2 \times 2 \times 3 \\ \hline & 40 = 2 \times 2 \times 2 \times 5 \\ & 33 = 3 \times 11 \\ & 21 = 3 \times 7 \end{array}$$

As all the factors above the line cancel, the division can be made. Multiplying the uncancelled factors below the line together we get $2 \times 5 \times 3 = 30$, therefore in order to make the division it will be necessary to index forward 30 spaces in the 33-hole circle, and then index backward 30 spaces in the 21-hole circle, as $30/21 - 30/33 = 330/231 - 210/231 = 120/231$, which is equivalent to indexing forward 120 spaces in a circle having 231 holes, and 120/231 of $1/40 = 120/9240 = 1/77$, the required division.

These moves may be simplified in a great many cases by adding algebraically any number of whole turns, a part of a turn, or a whole turn and a part of a turn, with a minus sign prefixed to the forward move, and the same amount with a plus sign prefixed to the backward move. Thus in the example just given we may add one whole turn as follows. One complete turn will equal 33/33 and 21/21, and the operation will be as follows:

$$\begin{array}{r} +30/21-30/33 \\ -21/21+33/33 \\ \hline +\ 9/21+\ 3/33 \end{array}$$

As both signs in the result are the same it indicates that the two moves will be in the same direction, and we would index forward 9 spaces in the 21-hole circle and then forward 3 spaces in the 33-hole circle.

Take another example. Suppose it is required to make 57 divisions. We will select circles having 19 and 15 holes.

$$\begin{array}{rr} & 57 = \not{3} \times \not{19} \\ 19-15= & 4 = \not{2} \times \not{2} \\ \hline & 40 = \not{2} \times \not{2} \times 2 \times 5 \\ & 19 = 1 \times \not{19} \\ & 15 = \not{3} \times 5 \\ \hline & 2 \times 5 \times 5 = 50 \end{array}$$

As all the factors above the line cancel, the division can be made with the circles selected, so we would have + 50/15−50/19, or in other words, would index forward 50 spaces in the 15-hole circle and backward 50 spaces in the 19-hole circle. As counting this number of holes would be very inconvenient, we will add, as before described, three whole turns = 45/15 and 57/19. We will then have

$$\begin{array}{r} +50/15-50/19 \\ -45/15+57/19 \\ \hline +\ 5/15+\ 7/19 \end{array}$$

and we would index forward 5 spaces in the 15-hole circle, and forward 7 spaces in the 19-

hole circle. As a proof $5/15 + 7/19 = 200/285$, and $200/285$ of $1/40 = 200/11400 = 1/57$, the division required.

There is no rule that can be given for the selection of the circles, or the selection of the number of turns to be added in order to simplify

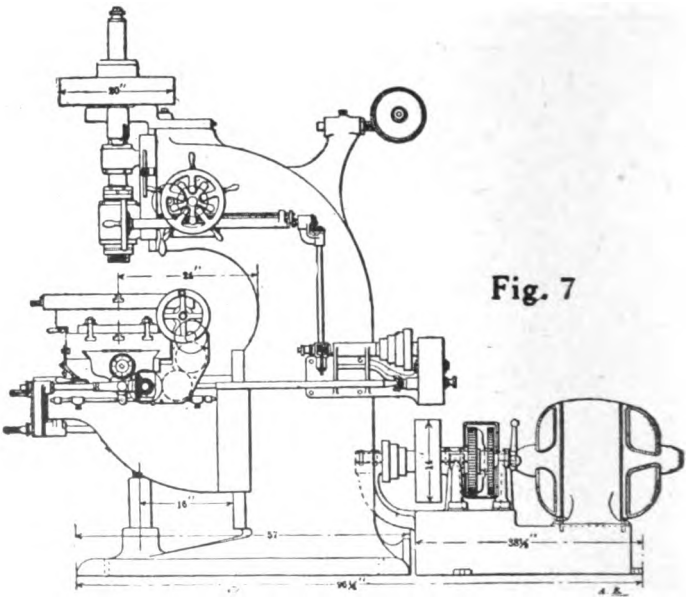


Fig. 7

the result, these factors depending wholly upon the judgment of the party making the calculations.

The spindle head B is mounted on the base V so that it may be rotated about its center, thus enabling the spindle to be elevated or depressed from its horizontal position. The

range of adjustment is generally somewhat more than 90°, although some heads are so constructed that they may be turned through more than 180°. This adjustment allows a great variety of angular work to be performed, such as cutting bevel gear teeth. To facilitate the adjustment of the head, it is graduated in degrees.

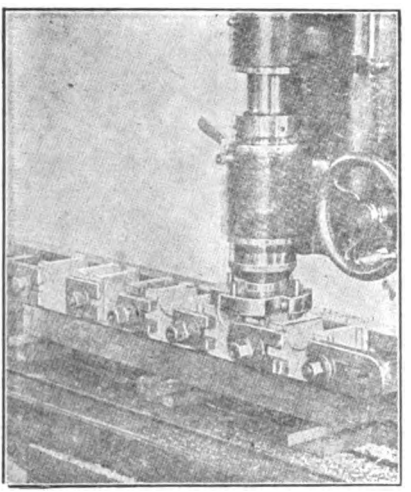


Fig. 8

When it is required to rotate the spindle while the cutter is operating upon the work, as is necessary when cutting spirals, a combination of gears between the worm shaft and the table feed screw is provided. These gears are shown at *S* in the various figures. As before mentioned, the sleeve *K* carries a gear *R* which

meshes with spur teeth on the bevel gear *P*. This gear meshes with bevel gear *Q*, which is on a shaft driven by the train of gears *S*. If the stop pin *U* is engaged with the index plate *L*, and the back stop pin *O* is released, it is evident that the rotation of the worm, and therefore the spindle, will be governed by the gear train *S*.

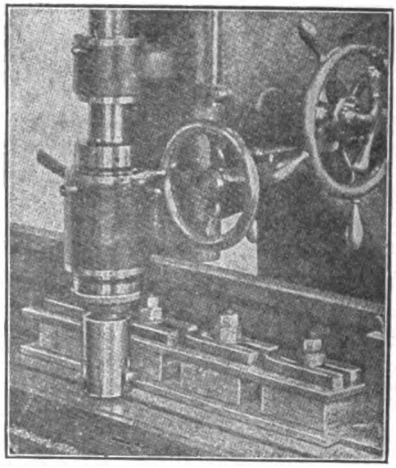


Fig. 9

It is also evident that when the feed screw *j* is at rest, the plate *L* will be prevented from turning without the pin *O* being engaged, and the required divisions may be obtained in the usual manner.

All machines are furnished with a table for determining the correct change gears to use for producing a large number of spirals of

different pitches. Any desired pitch of spiral may be produced by making special gears, and a number of pitches not given in the table may be produced by different combinations of gears. When such a table is missing, or when a spiral having a pitch not found in the table is to be cut, the correct gears may be found as follows:

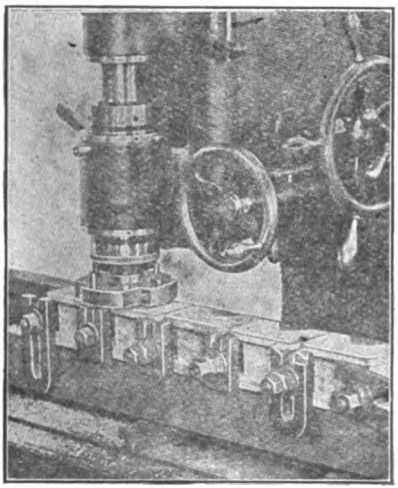


Fig. 10

Multiply the pitch of the table feed screw by the pitch of the spiral and place the product as the numerator of a fraction having the number of turns of the worm necessary to turn the spindle once for the denominator. Generally this last number will be 40. This fraction will denote the ratio existing between the number of teeth

in the gear on the dividing head and the number of teeth in the gear on the feed screw.

Thus, if a spiral pitch of 10 inches is required to be cut, and the feed screw is 4 pitch, the fraction would be $\frac{10 \times 4}{40} = \frac{40}{40}$; therefore, equal gears on the head and screw would pro-

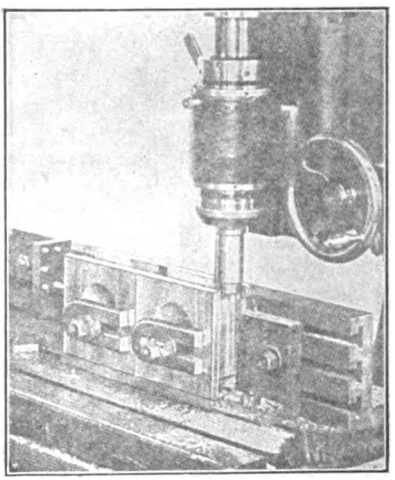


Fig. 11

duce it. In fact, the process of calculation is exactly the same as was described for calculating the change gears for screw cutting. Generally, it will be found necessary to compound the gears, but wherever possible single gears should be used.

With the arrangement of gears shown in Fig. 2, the machine will cut a right hand spiral.

If a left hand spiral is required an extra gear must be placed in the train, thus changing the direction of rotation of the spindle.

In the cutting of all spirals, the work table must be set at an angle with the axis of the cutter spindle, so that the cutter will be tangent to the line of the spiral. The amount of this off-set is equal to the spiral angle of the work, and may be determined graphically, or by calculation. The first method is as follows (see Fig. 5):

On any plane surface draw two lines *a*, *b* and *c*, *d* at right angles to each other. From *e*, the point of intersection, lay off on line *c*, *d* a distance *e*, *f* equal to the pitch, or lead, of the spiral. From *e* on line *a*, *b* lay off a distance *e*, *g* equal to the circumference of the work. Join points *g* and *f* and the angle *g*, *f e* will be the required angle for the table.

To calculate the angle *divide the circumference of the work by the lead of the spiral.* The result will be the natural tangent of the required angle, and the angle may be found by consulting a table of natural tangents. Thus, if it is required to cut a spiral of 6 inches pitch, on a cylinder 2 inches in diameter, we would have $\frac{3.1416 \times 2}{6} = 1.0472$. Looking in a table of natural tangents we will find that 1.0472 is the tangent of the angle of 46° 15′, nearly.

From the foregoing it will be readily seen that the angle to which the table must be set depends on the lead of the spiral and the diam-

eter of the work. With a given lead the angle will increase as the diameter of the work increases.

In cutting spiral grooves, the sides of which are required to be parallel, an end mill must be used, and when angular grooves are to be milled, double angle cutters must be used if the result-

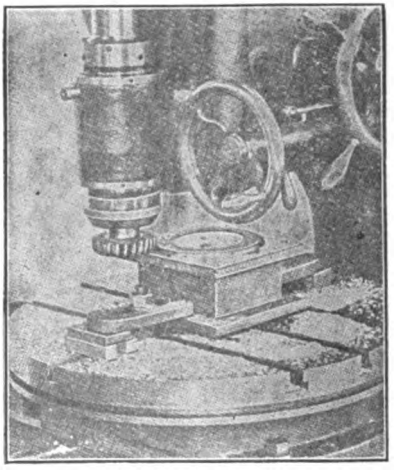


Fig. 12

ing groove is to be a counterpart of the cutter. As a great deal of spiral milling requires that one side of the groove be radial, it is necessary to use a double angle cutter, and set it "off center" sufficiently to make the required side of the groove radial when the cutter has entered the work the required depth. The distance that the cutter must be off-set may be found by the following rule:

Multiply one-half of the diameter of the work at the bottom of the cut by the sine of the angle included between that side of the cutter with which the radial side of the groove is to be cut and a plane perpendicular to the axis of the cutter. Following is the table, which is approximately correct, having been calculated by the rule above, except that the depth of the cut was not taken into consideration.

Angle of Cutter	Off-set.
12°	Diameter x 0.1
27½°	Diameter x 0.23
30°	Diameter x 0.25
40°	Diameter x 0.32
45°	Diameter x 0.35
48°	Diameter x 0.37
53°	Diameter x 0.4

In cutting spiral grooves the work should be rotated toward the side of the cutter having the greatest angle, and care must be taken that the work is securely held so that it cannot slip in any direction, as such slip will be sure to spoil the work, and also the cutter and arbor.

Milling machine cutters are made in a variety of forms, but may be classified generally as plain cutters; side, face or butt mills; angular cutters, end mills, and formed cutters. In Fig. 6 is shown a number of these cutters. No. 1 is what is generally called a slitting saw, and is used for cutting off stock, and milling narrow grooves, etc. It is clamped between washers on an arbor. They are made in a variety of widths and diameters, and are the simplest form of milling cutter. No. 2 is a

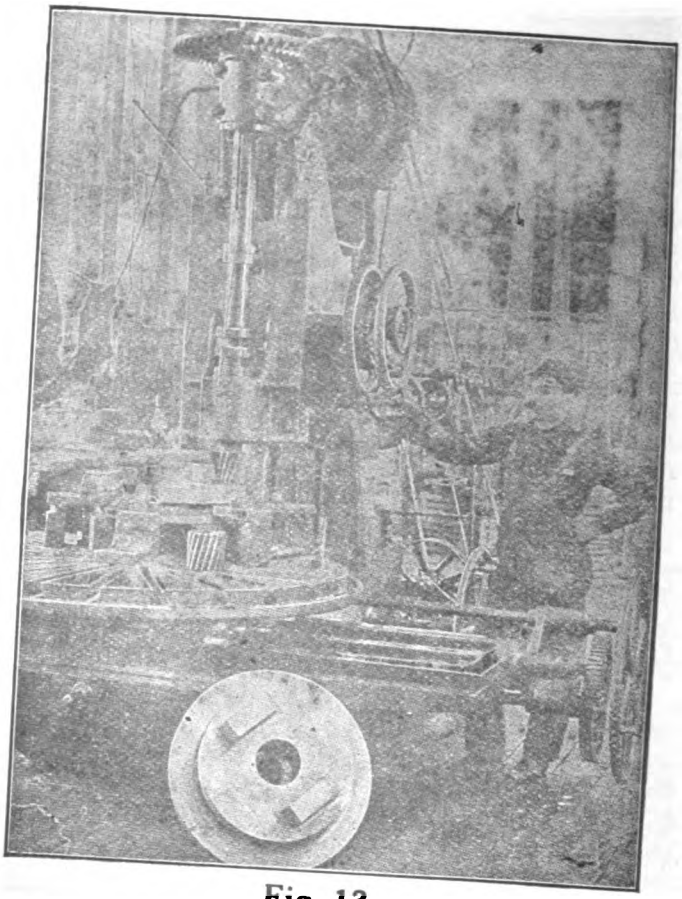


Fig. 13

plain, wide-faced cutter with helical, or as they are commonly called, spiral cutting edges. This cutter is used for plane surfaces. No. 3 is the same style of cutter, except that the teeth are nicked for the purpose of breaking up the chips. In large sizes these cutters are made with inserted teeth. No. 4 is a side milling cutter used for facing work surfaces which stand at a right angle to the axis of the cutter. No. 5 is the same style of cutter, except that the body is made of soft steel with the teeth inserted in slots. Nos. 6 and 7 are examples of formed cutters, the ones shown being used for cutting gear teeth. No. 8 is an example of an end mill used for cutting grooves, etc. Milling cutters are made in almost every conceivable shape, and are also mounted in gangs on the arbor, as will be shown in the examples given later.

The making of correctly formed milling cutters is a trade by itself—lack of space will not allow it to be taken up, but it will well pay any machinist to get all the information he can regarding it.

In order to do good milling it is absolutely necessary that the cutters be kept sharp, and also that they are so ground that *all* the cutting edges are the same distance from the axis of rotation. This latter condition calls not only for the cutters to be ground true, but that the arbors upon which they are mounted must be kept true. A correctly ground cutter mounted upon an arbor which does not run true will not do good work. Notwithstanding this fact it is

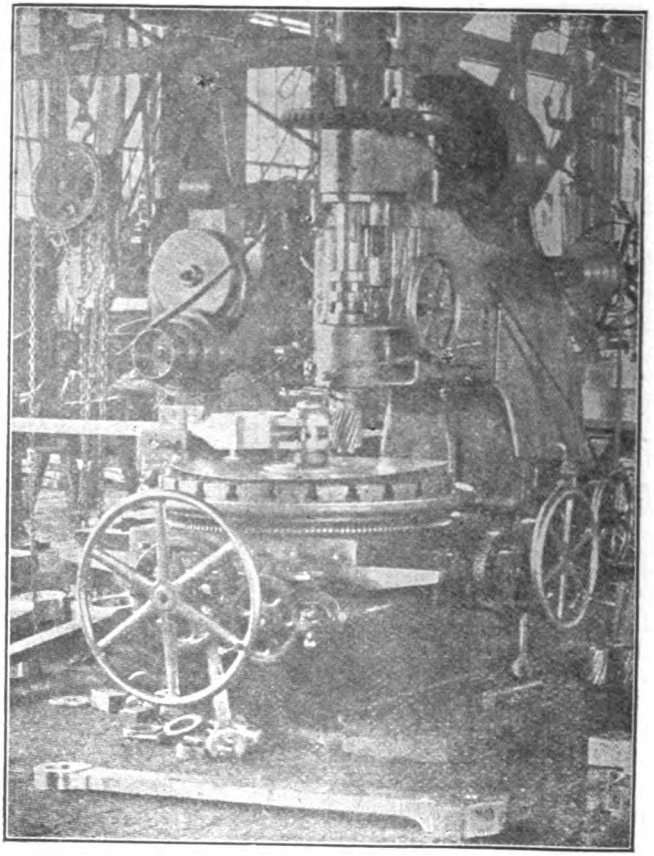


Fig. 14

altogether too common a sight to see milling cutters grinding away with perhaps only two or three teeth doing the cutting. To keep milling cutters in condition, a grinding machine is an absolute necessity.

Generally the milling cutters are mounted on an arbor which is fitted to the tapered hole in

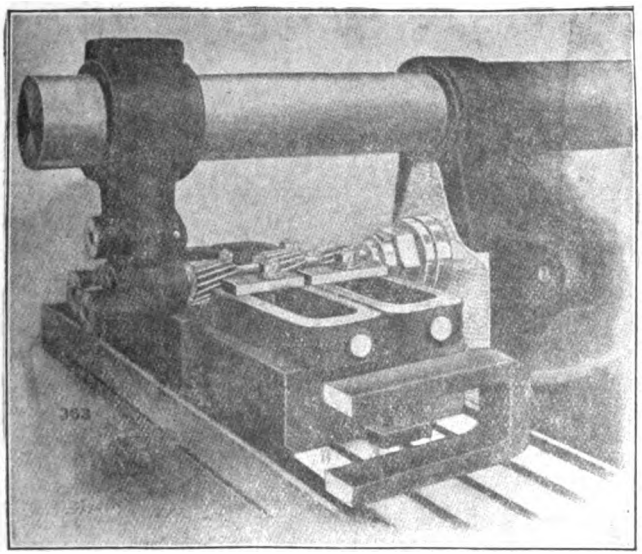


Fig. 1[illegible]

the spindle, and, except in the smaller sizes, they are driven by a key. The arbors are supplied with washers of various lengths, between which the cutter is placed and held by a nut on the end of the arbor. Care should be taken to see that the direction of rotation of

the cutter and the thread on the arbor are such that any tendency of the cutter to slip will tend to tighten the nut. Before placing an arbor in position, the hole in the spindle and the shank of the arbor should be thoroughly cleaned of all chips and grease. The arbor should be placed in the spindle so that the

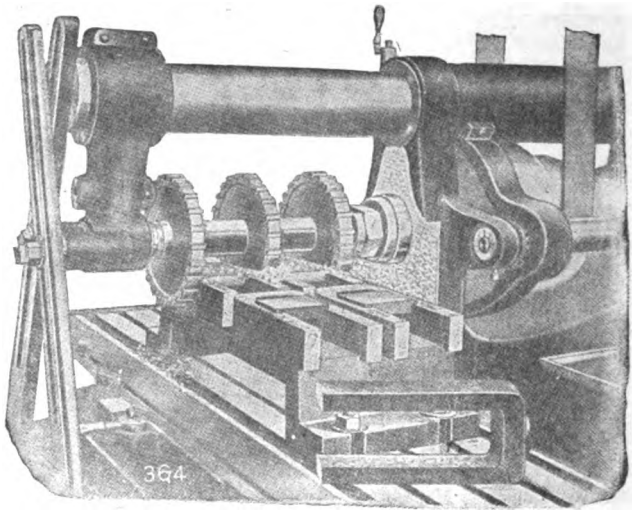


Fig. 16

tang will enter the slot in the spindle, and should be driven home by a fair blow with a heavy soft hammer. The presence of oil between the arbor and the hole in the spindle will make it impossible to keep the arbor tight, and unless evenly distributed it will cause the arbor to run out of true.

Work is held in the milling machine in much

the same manner as has been described for other machine tools, and the same considerations relative to the clamping and setting will apply. Generally speaking, work must be more securely fastened in the milling machine as the pressure of the cut is greater; also, there will be greater tendency for the pressure of the cut to spring the work. As the milling machine shows to the best advantage on duplicate work, special work holding devices and jigs should be made use of wherever possible.

In the matter of the proper cutting speed for milling operations, there will be a great difference, owing to the great variety of work done, but, generally speaking, the speeds will be somewhere between 15 and 25 feet per minute for hard steel; 30 to 40 feet per minute for soft steel, wrought iron and hard castings; 50 to 60 feet per minute for soft castings, bronze, etc., and from 80 to 100 feet per minute for brass. This cutting speed is the peripheral speed of the cutter, and is found by multiplying the circumference of the cutter in feet by the number of revolutions per minute.

The rate of feed to be used will depend on the pitch of the cutter teeth and the provisions made for keeping the cutter clear of chips; also, on the character of the work, the manner in which it is held to the table, and the degree of finish which is required. The latter requirement will, in a great many cases, be the governing factor. The examples of milling operations which will be given later will give the reader a

good idea of what is being accomplished in this matter in various shops.

All modern milling machines are provided with means for copious lubrication of the cutter teeth for the purpose of keeping them cool. In cutting common cast iron and brass no lubrication is necessary, or desirable, but generally all

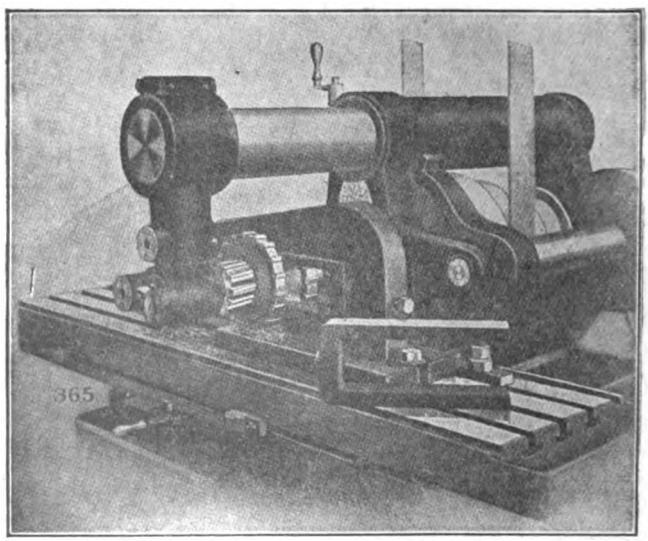


Fig. 17

other materials will require it if the maximum output from the machine is desired.

In the following pages some examples of modern milling machines will be given, together with the class of work performed on them in the various railway shops, the author believing this

to be the best way of showing the adaptability of the various machines to railway work.

Fig. 7 shows a vertical spindle milling machine, the position of the spindle and the circular table feed making it peculiarly suited for certain kinds of work. The vertical movement of the head is actuated automatically by a

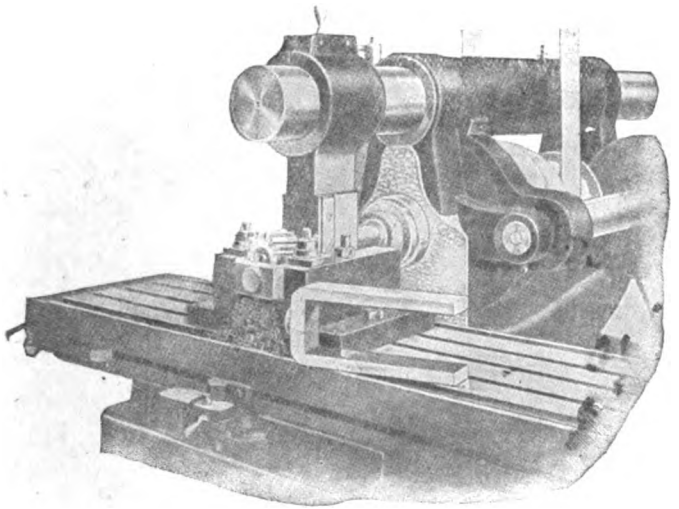


Fig. 18

worm gear, and for boring purposes it is provided with an automatic stop which will throw out the feed at any pre-determined point. It is also provided with a quick return motion. A micrometer stop gauge at the upper left hand side of the head accurately gauges the depth of the cut. The end of the spindle is threaded to

hold large surface mills, while medium and small cutters are held by an arbor or bar passing through the hollow spindle. The table has two feeds at right angles to each other, and also has a rotary feed similar to that of the slotter. All of these feeds may be operated by hand or automatically, and are provided with stops for throwing out the feeds.

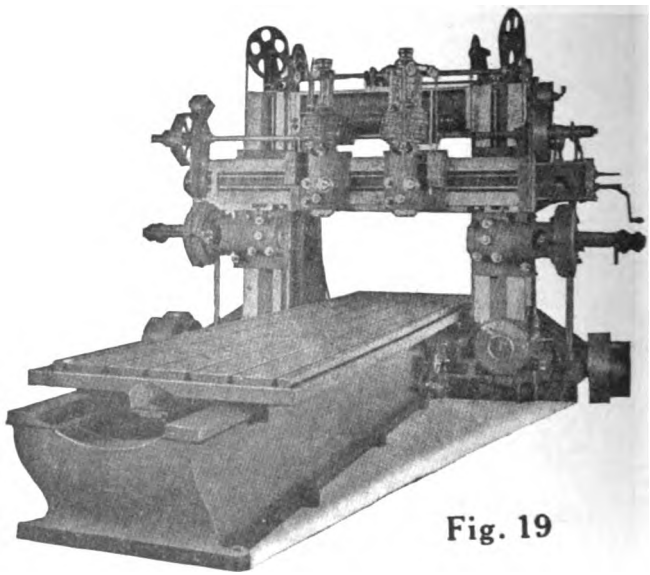


Fig. 19

Figs. 8 to 12, inclusive, show this machine performing the operations necessary to finish a group of rod brasses. Fig. 8 shows the finishing of the joint surfaces with an inserted tooth face mill. The table feed is at the rate of 7 inches per minute. Fig. 9 shows an inserted

tooth cutter finishing the inside of the lower flange, the table feed being 3½ inches per minute. The upper flanges are finished at this setting by changing the cutter. Fig. 10 shows the sides of the brasses being finished with the same tool as was used in the operation shown in

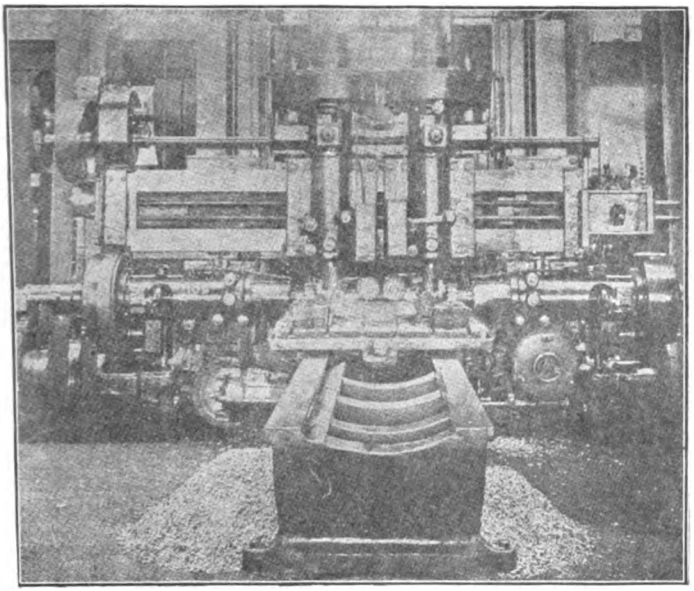


Fig. 20

Fig. 8, but a somewhat slower feed should be used. The brasses are then turned over and the other side finished. Fig. 11 shows an inserted tooth cutter finishing the bottom of the rod fit. This requires two cuts for each side with a table feed of 4 inches per minute. The tops of the

flanges are finished at this setting with separate cuts with the same rate of feed. Fig. 12 shows the side of the brass and fillet being finished with a round-nosed cutter, the circular table feed being used.

Fig. 13 shows a back cylinder head being finished, and a finished head is shown leaning against the machine. This job is generally considered one for the planer, and on account of

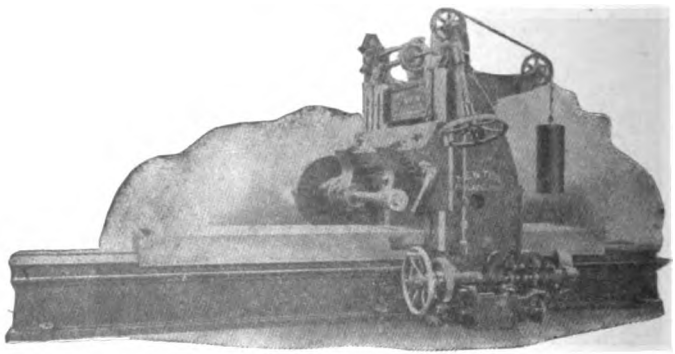


Fig. 21

the lugs for the guides would have to be set twice and planed in two directions. Unless the setting is very carefully done the finish will be poor and it will take about 5 hours to do it. On the vertical milling machine two cutters are used, one for finishing the plane surface, and a bevel cutter for finishing the lugs to the required angle. By this means it is possible to finish the head in 2½ hours.

Fig. 14 shows a vertical milling machine at

work finishing the ends of side rods. This work is generally done on the slotter, but the vertical miller will do it much quicker and better.

Figs. 15, 16, 17 and 18 show the various operations of finishing connecting rod straps on a plain or universal milling machine. The first operation is shown in Fig. 15, and consists of

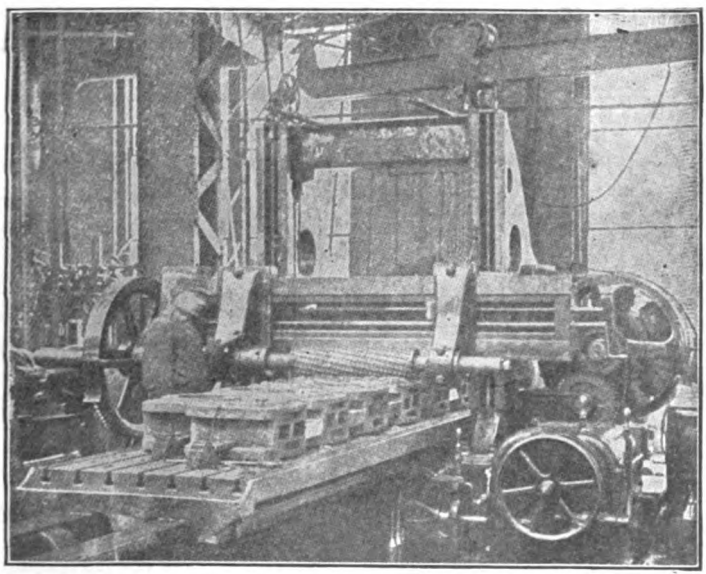


Fig. 22

finishing the ends of four straps at one time. The straps are clamped in a jig as shown, and the ends are faced by using three plain cutters and the power vertical feed. The cutters are high speed steel, both sides being used at the same time. In the illustration shown, the length

of the cut is $2\frac{1}{2}$ inches, total width about 7 inches, depth of cut $\frac{1}{4}$ inch to $\frac{3}{8}$ inch. By this method the ends of 16 straps are finished per hour.

Fig. 16 shows how the sides of four straps are finished at one setting. The straps are clamped in a jig, and are operated upon by three inserted tooth cutters $8\frac{1}{2}$ inches in diameter. The cutting

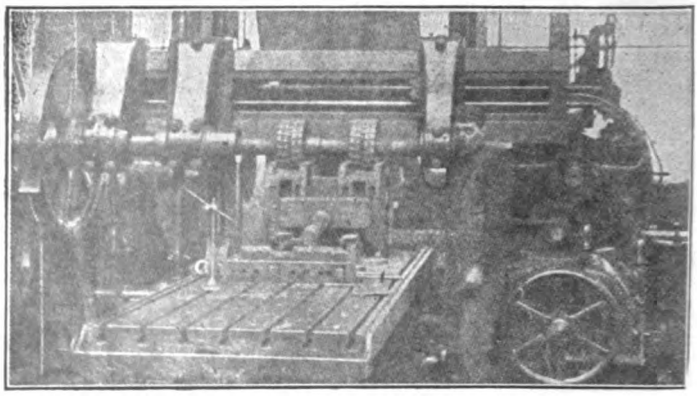


Fig. 23

speed is 50 feet per minute, and the table feed is 1 inch per minute. This operation is completed on 12 straps per hour.

Fig. 17 shows the operation of finishing the edges of the strap, and cutting out the inside at the same time. The machine is shown in the position to take the first, or roughing cut, which roughs out the inside surfaces and finishes the edges. The inside cutter cuts the top and bot-

tom at the same time. For the second and finishing cut, the work is brought in position with the finishing cutter (shown at the left) which is made with adjustable blades so that it may be maintained at standard size. This cut is taken with a table feed of 0.03-inch per revolution of the cutter. This operation may be completed on two straps per hour.

Fig. 18 shows the final operation, which is that of finishing the inside end. The cutter cuts on both the end and the periphery, and is

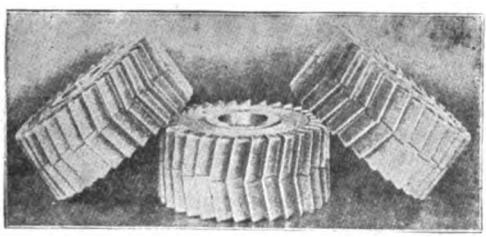


Fig. 24

of the adjustable blade type. The table feed for this operation is 0.012-inch per revolution of the cutter, using the power vertical feed. This operation is performed on 12 straps per hour.

Fig. 19 shows a four-spindle, planer type of milling machine; and Fig. 20 shows this machine milling locomotive connecting rods. The edges of the rods are finished by the cutters held in the vertical heads. The flute is cut by the cutters held in the side heads, while the sides of the body of the rod, and the sides of the

stub ends, are milled by the two cutters shown lying on the table, these cutters being carried in the side heads. For milling the flutes, inserted blade cutters 8 inches in diameter and the width of the flutes are used, at a speed of 50 feet per minute, with a table feed of $1\frac{5}{8}$ inches per minute, or 0.065 inch per revolution of the cutter. As the bodies of the connecting rods

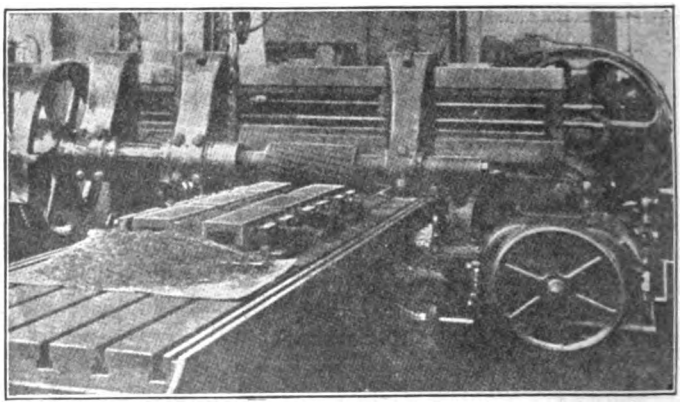


Fig. 25

are tapered, as well as the flutes, it is necessary to set one edge of the rod straight and mill one edge of the rod and one side of the flute, then re-set the rod and mill the remaining edge and finish the flute. The rod is then turned over and the other side finished in the same manner, thus requiring the table to be fed the length of the rod six times. Parallel rods, being straight, will not require re-setting.

Fig. 21 shows another form of planer type milling machine having only one cutter spindle. This machine is intended for the heaviest class of surface milling. Figs. 22 and 23 show this machine at work on driving boxes. Fig. 22 shows the sides of the boxes being milled with a high-speed steel inserted tooth cutter, 8 inches in diameter and 30 inches long. Twelve boxes

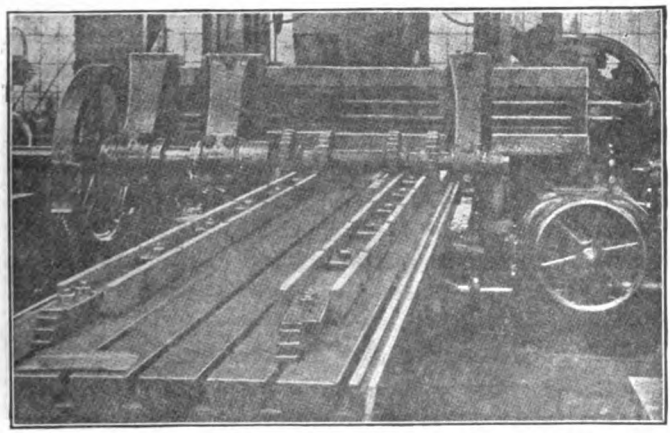


Fig. 26

are placed on the machine at one time. On cast steel the cutting speed is about 50 feet per minute, with a table feed of $1\frac{3}{8}$ inches per minute. The depth of cut is about $\frac{1}{2}$ inch. In milling cast steel it is absolutely necessary to keep the cutter thoroughly lubricated with soda water or compound. Fig. 23 shows the operation of machining the shoe and wedge fits. In this case two boxes are clamped to a jig similar to

the one shown for this purpose for use upon the planer. The cutters are of the inserted tooth, interlocking type, 12″ in diameter. A group of these cutters is shown in Fig. 24. The cutters are made in halves, the teeth of one half interlocking with, or overlapping those of the other half. As the cutters are ground, washers are placed between the two halves, thus keeping the width constant. In cutting

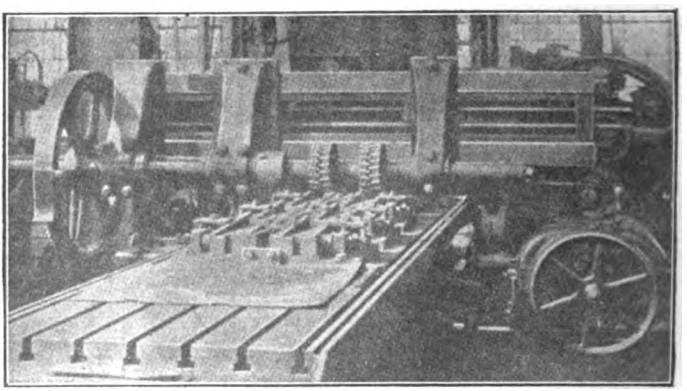


Fig. 27

cast iron, these cutters are run about 12 revolutions per minute, with a table feed of $1\frac{3}{8}$ inches per minute, while in cutting cast steel they may be run at 15 revolutions per minute, with a table feed of $\frac{5}{8}$ inch per minute.

Figs. 25, 26 and 27 show the various operations of milling shoes and wedges. The first operation, shown in Fig. 25, consists in milling the driving box face. For this purpose the

shoes or wedges are held in a suitable jig. The cutter used is of the inserted tooth type, 8″ in diameter and 18″ long. It is run at 12½ revolutions per minute, with a table feed of 2¾ inches per minute. This high rate of feed will not give a smooth finish, but as this face of the shoes and wedges must be later planed to lines, the finish is immaterial. The second operation,

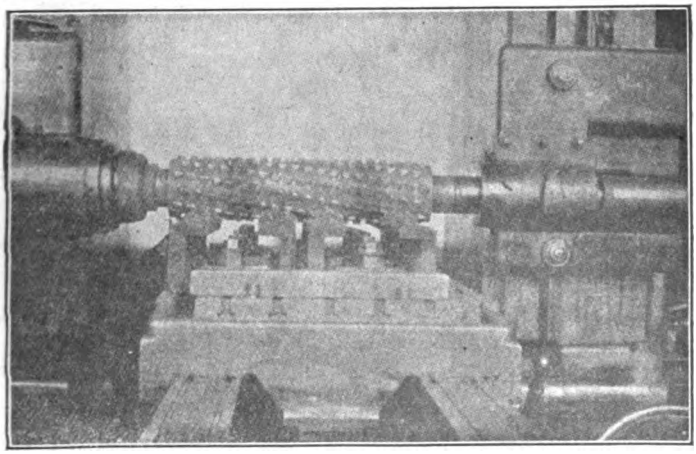


Fig. 28

shown in Fig. 26, consists of milling the two side faces and the tops of the flanges. Two rows of shoes or wedges are placed on parallel strips and clamped, as shown. The sides and tops of the flanges are milled at one operation by the gang cutters, consisting of the large cutters, 13″ in diameter, of the inserted tooth type, while the small cutters are solid and 6″

in diameter. They are run 12½ revolutions per minute with a table feed of 15-16 inch *per* minute. The third operation consists of finishing the inside surfaces, and is shown in Fig. 27. The shoes or wedges are held in the same jig that was used for the first operation. The cutters used are 12″ in diameter and are of the

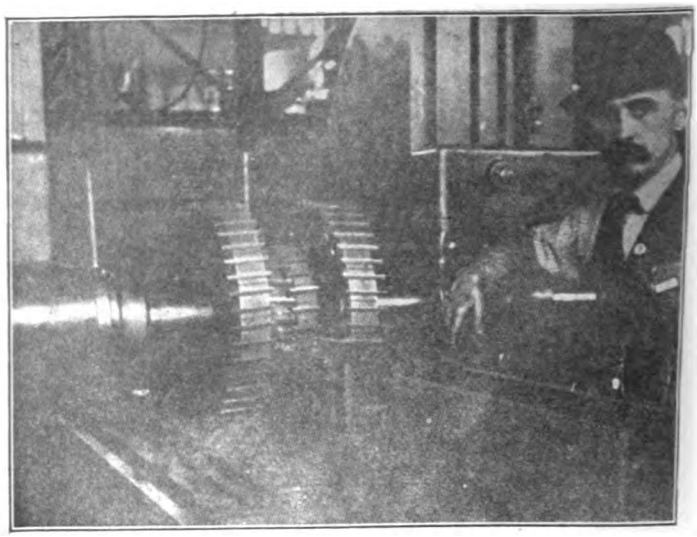


Fig. 29

inserted tooth, interlocking type, so that they are adjustable in width. These cutters are run 12 revolutions per minute with a table feed of 1⅜ inches per minute.

Figs. 28 and 29 show two other methods of handling shoes and wedges. In the first, four rows of them are shown, set to have the sides

of the flanges finished. This is done by a large plain cutter with inserted teeth. Fig. 29 shows seven surfaces being finished at one setting with a gang of six cutters. This operation is a combination of the two shown in Figs. 26 and 27.

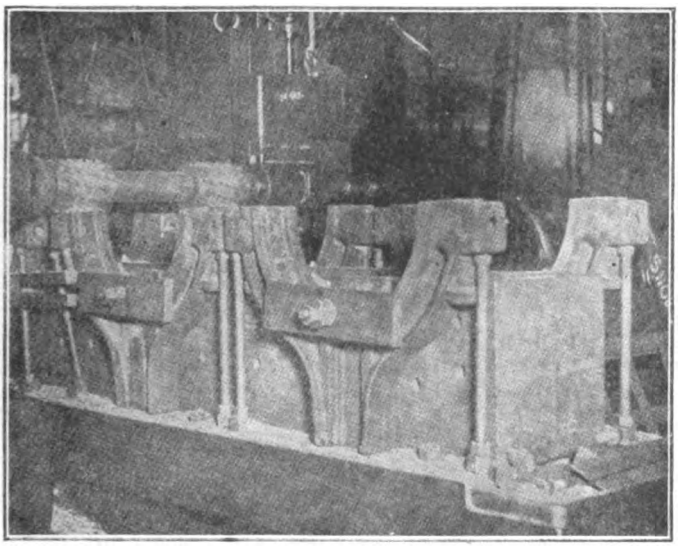


Fig. 30

Fig. 30 shows a method of milling the joint surfaces of eccentric straps, and needs no further explanation. In a similar manner the eccentric halves may be machined at a great saving of time over that required by the planer.

As will be noticed from the foregoing, the

milling machine differs from the other machine tools in the matter of the rate of feed. In the case of the planer, shaper, etc., the finishing cuts are generally taken with a very coarse feed, while if the maximum accuracy of finish is desired from the milling machine, the rate of feed for the finishing cut must be small. For the roughing cut on a milling machine, a comparatively slow cutting speed and heavy feed should be used, and the finishing cut should be taken with a faster cutting speed and finer feed. As with all machine tools, these factors are matters for experiment in order to determine the most economical rate of cutting speed and feed, taking into consideration the character of the work, type of machine available, etc.

CHAPTER XXIII.

Machine Work—Something About Gear Cutting.

The subject of gear cutting is one with which, as a general thing, the machinist engaged in railway work has very little to do. Such being the case, it is not at all surprising that the average railway machinist knows very little about it. In the following pages will be given, briefly, enough of the principles governing the design of gear wheels to enable the machinist to solve such problems as are likely to come up in the shop.

Referring to Fig. 1, if a pair of friction wheels roll freely upon each other, the number of revolutions will bear an inverse ratio to the diameters of the respective wheels. This ratio is called the velocity ratio of the wheels. Thus, if we call wheel A the driver and wheel B the driven, and

D = diameter of driver
d = diameter of driven
N = number of revolutions of driver
n = number of revolutions of driven then

$$\frac{n}{N} = \frac{D}{d} \text{ and } n = \frac{dN}{d};\ N = \frac{dn}{D};\ d = \frac{ND}{n};\ D = \frac{dn}{N}.$$

These equations are the fundamental ones governing the relationship existing between

any pair of friction wheels so long as there is no slipping between the surfaces in contact.

In the case of gear wheels this relationship is the same, for the reason that the surfaces which, in the case of friction wheels, form the actual surfaces in contact are used in gear wheels in the form of *imaginary* surfaces upon which the forms of the teeth are laid out. Thus, in each pair of gear wheels there are two circles struck from the centers of the wheels, which have at each moment the same linear

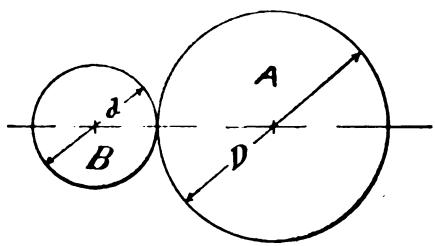


Fig. 1

velocity and which are called in general the ratio circles. *The particular ratio circle for any gear wheel is called the pitch circle,* and upon the circumference of this circle are laid out the spacings from center to center of the teeth.

The teeth of gear wheels are made in two forms, shown in Fig. 2. The form shown at the left is known as the *involute,* while the one shown at the right is known as the *cycloidal* or *epicycloidal.* The first form has the advantage of working correctly if the center to center distance between the gears is not absolutely

correct, and should always be used in cases where this center to center distance is not fixed, as in the case of the change gears for the lathe and milling machine.

Referring to Fig. 2, the part of the tooth outside of the pitch circle is called the *addendum*, and the wearing surface of this portion of the tooth is called the *face* of the tooth.

The portion of the tooth lying inside of the pitch circle is called the *dedendum*, and the

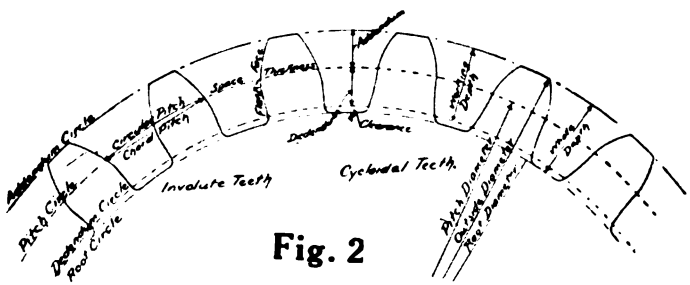


Fig. 2

wearing surface of this portion of the tooth is called the *flank* of the tooth.

The point in the pitch circle at which the face and flank meet is called the *pitch point.*

The circle passing through the tops of the teeth is called the *addendum circle,* and the diameter of this circle is equal to the *outside diameter* of the gear blank.

The circle passing through the bottoms of the teeth is called the *root circle.* The radius of this circle is equal to the radius of the addendum circle less twice the addendum plus the clearance.

The *circular pitch* is the distance between the centers of two adjacent teeth *measured on the pitch circle,* and is equal to the circumference of the pitch circle divided by the number of teeth in the gear.

As the circumference of the pitch circle is equal to its diameter, multiplied by 3.1416, it will be seen that if the circular pitch be made equal to some number which can be easily measured with common shop tools, the diameter of the gears, and consequently the center to center distance between them, will be a number not easily measured with ordinary shop tools. For this reason it is customary to make the pitch diameters of the gears some easily measured number, and thus the circular pitch will be fractional. This method of constructing gears has led to the almost universal use of the *diametral pitch.*

The diametral pitch is not, correctly speaking, a measurement, but is, as generally expressed, the ratio existing between the number of teeth in the gear and the diameter in inches of the pitch circle. In other words, it is the number of teeth in a gear having a pitch circle one inch in diameter. Thus, if a gear has 28 teeth and the pitch circle is 4 inches in diameter, the diametral pitch $= \frac{28}{4} = 7$.

From the foregoing it follows that all teeth of any given diametral pitch are of the same size, and will run together whatever the size of the gears may be. Fig. 3 shows the comparative sizes of teeth of various diametral pitches.

In all diametral pitch gears the addendum is made equal to 1 divided by the diametral pitch, and the working depth of the teeth is equal to twice the addendum. The end clearance given by different makers varies. The

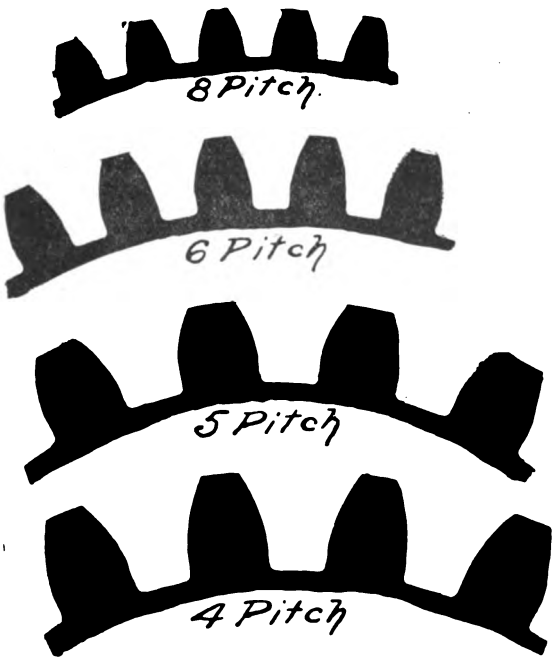


Fig. 3

Brown & Sharpe Co. make this clearance equal to 1-10 of the thickness of the tooth on the pitch line, while the Pratt & Whitney Co. make it equal to $\frac{1}{8}$ of the addendum.

Following are the usual formulas used in spur gear calculations:

1. Diametral Pitch $= \frac{\text{Number of Teeth}}{\text{Pitch Diameter}} = \frac{\text{Number of Teeth} + 2}{\text{Diameter.}}$.

2. Pitch Diameter $= \frac{\text{Number of Teeth}}{\text{Pitch}} =$ Outside Diameter $- \frac{2}{\text{Pitch}}$.

3. Outside Diameter $= \frac{\text{Number of Teeth} + 2}{\text{Pitch}}$ $=$ Pitch Diameter $+ \frac{2}{\text{Pitch}}$.

4. Number of Teeth = Pitch Diameter $\times$ Pitch = (Outside Diameter $\times$ Pitch) $- 2$.

5. Pitch Circumference = Pitch Diameter $\times$ 3.1416.

6. Circular Pitch $= \frac{\text{Pitch Circumference}}{\text{Number of Teeth}} = \frac{3.1416}{\text{Pitch}}$.

7. Thickness of Tooth $= \frac{\text{Circular Pitch}}{2} = \frac{1.57}{\text{Pitch}}$.

8. Clearance $= \frac{0.157}{\text{Pitch}}$ or $\frac{1}{8 \text{ Pitch}}$.

9. Addendum $= \frac{1}{\text{Pitch}}$.

10. Working Depth of Tooth $= \frac{2}{\text{Pitch}}$ or $2 \times$ Addendum.

11. Whole depth of Tooth $= \frac{2.157}{\text{Pitch}}$ or $(2 \times$ Addendum) + Clearance.

There are several methods of cutting gear teeth in use, but the one most likely to be used by the railway machinist will be the one known as the formed cutter process, using either a

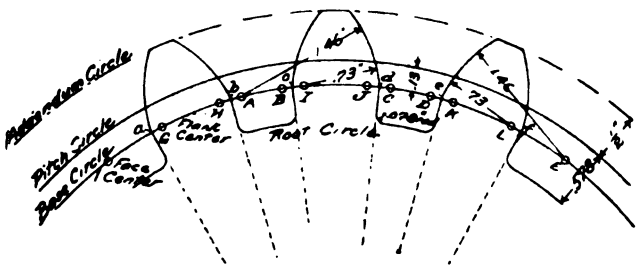


Fig. 4

formed cutter in the milling machine, or a formed tool in a planer or shaper.

All manufacturers of milling cutters make standard cutters for the involute form of tooth, and a number of them also make cutters for the cycloidal or epicycloidal form. In the cycloidal system each diametral pitch requires a set of 24 cutters to enable all gears from a 12 tooth pinion to a rack to be cut, while for the involute system, a set of 8 cutters are required for each pitch. The following table gives the designa-

tion of the different cutters as manufactured by the Pratt & Whitney, and Brown & Sharpe companies:

TABLE OF STANDARD CUTTERS.

CYCLOIDAL OR EPICYCLOIDAL.				INVOLUTE.	
Pratt & Whitney.		Brown & Sharp .			
Number of Cutter.	No. of Teeth in Gear.	Number of Cutter.	No. of Teeth in Gear.	Number of Cutter.	No. of Teeth in Gear.
1	12	A	12	1	135 to rack
2	13	B	13	2	55–134
3	14	C	14	3	35–54
4	15	D	15	4	26–34
5	16	E	16	5	21–25
6	17	F	17	6	17–20
7	18	G	18	7	14–16
8	19	H	19	8	12–13
9	20	I	20		
10	21–22	J	21–22		
11	23–24	K	23–24		
12	25–26	L	25–26		
13	27–29	M	27–29		
14	30–33	N	30–33		
15	34–37	O	34–37		
16	38–42	P	38–42		
17	43–49	Q	43–49		
18	50–59	R	50–59		
19	60–75	S	60–74		
20	76–99	T	75–99		
21	100–149	U	100–149		
22	150–299	V	150–249		
23	300 and over	W	250 and over		
24	Rack	X	Rack		

Referring to the table, if it is required to cut a gear having 25 teeth of the cycloidal form, we would require a No. 12 Pratt & Whitney cutter, or a No. L Brown & Sharpe cutter. If the teeth were of the involute form, a No. 5 involute cutter would be required.

The standard pitches for which involute cutters are furnished are as follows: $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, 2, $2\frac{1}{4}$, $2\frac{1}{2}$, $2\frac{3}{4}$, 3, $3\frac{1}{4}$, $3\frac{1}{2}$, $3\frac{3}{4}$, 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 20, 22, 24, 26, 28, 30, 32, 36, 38, 40, 44, 48, 50, 56, 60, 64, 70, 80 and 120.

Cycloidal cutters are furnished by the Pratt & Whitney Co. for the following pitches: $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, 5, 6, 7, 8, 9, 10. And the Brown & Sharpe Co., for the following pitches: 2, $2\frac{1}{4}$, $2\frac{1}{2}$, $2\frac{3}{4}$, 3, $3\frac{1}{2}$, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16.

It will be seen from the foregoing that to properly cut all sized gears for all the different pitches for which cutters are furnished would require a total of 368 cutters for the involute sytem, and 384 for the cycloidal system.

As the gear cutting that the railway machinist will be called upon to do will generally consist of making new gears to replace broken ones, the following problem will make the application of the foregoing formulas clear.

It is required to make a gear to replace a broken one which has 14 teeth of the involute form, and which measures, as near as can be determined, $4\frac{1}{4}$ inches, outside diameter. It is required to find the actual outside diameter, the diametral pitch, and the number of cutter required. We will also need to know the whole depth of the tooth. If the correct cutter is not at hand, it will be necessary to make one, and therefore the shape of the tooth will have to be laid out and a template made for shaping the tool.

First determine the diametral pitch by formula 1.

$$\text{Pitch} = \frac{14 + 2}{4\frac{1}{4}} = 3.76; \text{ say } 3\tfrac{3}{4}.$$

In applying this formula, it will often be found, as in this case, that the result obtained

will not agree with any standard pitch. The result above, 3.76, is so near $3\frac{3}{4}$, that it is evident that the pitch of the gear in question is $3\frac{3}{4}$, and that the error is either in not determining accurately the exact outside diameter of the old gear, or it was originally not turned to the correct diameter. Possibly the tops of the teeth may have been worn off more or less. If there is a considerable difference between the calculated pitch and the nearest standard pitch, it will indicate that the gear is not based on the diametral pitch, or that an uncommon pitch was used. This will be more likely to be the case with cast gears, as all cut gears are based on diametral pitches.

To check the above calculation, and also to find the actual outside diameter of the gear blank, use formula No. 3.

$$\text{Outside diameter} = \frac{14 + 2}{3\frac{3}{4}} = 4.266''.$$

As the gear has 14 teeth, we would want a No. 7 cutter. The whole depth of the tooth, or the depth the cutter must enter the blank, will be found by formula No. 11.

$$\text{Whole depth of tooth} = \frac{2.157}{3\frac{3}{4}} = .575''.$$

In case a suitable cutter is at hand we now have all the necessary data to enable the gear to be cut. If no cutter is at hand it will be necessary to make one, either a formed planer or slotter tool, or a cutter for the milling machine. In order to get the correct shape of the

tooth the following construction, taken from Grant's Treatise on Gear Wheels, will be necessary:

In the involute system the curved portion of the tooth outline is laid out from the circumference of a circle called the *base circle.* The radius of this circle is less than that of the pitch circle by an amount which is generally found by multiplying the diameter of the pitch circle by a constant factor. This factor varies with different makers, but will be about 1-60 of the diameter of the pitch circle. For all gears having less than 37 teeth, the curved portions of the tooth outline on each side of the pitch circle are drawn with different radii, the centers of the arcs being located on the base circle. The lengths of these radii are obtained from the following table, bearing the heading "Involute Odontograph":

INVOLUTE ODONTOGRAPH.

Teeth.	Divide by the Diametral Pitch.		Multiply by the Circular Pitch.	
	Face Radius.	Flank Radius.	Face Radius.	Flank Radius.
10	2.28	.69	.73	.22
11	2.40	.83	.76	.27
12	2.51	.96	.80	.31
13	2.62	1.09	.83	.34
14	2.72	1.22	.87	.39
15	2.82	1.34	.90	.43
16	2.92	1.46	.93	.47
17	3.02	1.58	.96	.50
18	3.12	1.69	.99	.54
19	3.22	1.79	1.03	.57
20	3.32	1.89	1.06	.60
21	3.41	1.98	1.09	.63
22	3.49	2.06	1.11	.66
23	3.57	2.15	1.13	.69
24	3.64	2.24	1.16	.71
25	3.71	2.33	1.18	.74
26	3.78	2.42	1.20	.77
27	3.85	2.50	1.23	.80
28	3.92	2.59	1.25	.82
29	3.99	2.67	1.27	.85
30	4.06	2.76	1.29	.88

Teeth.	Divide by the Diametral Pitch		Multiply by the Circular Pitch.	
	Face Radius.	Flank Radius.	Face Radius.	Flank Radius.
31	4.13	2.85	1.31	.91
32	4.20	2.93	1.34	.93
33	4.27	3.01	1.36	.96
34	4.33	3.09	1.38	.99
35	4.39	3.16	1.39	1.01
36	4.45	3.23	1.41	1.03
37–40	4.20		1.34	
41–45	4.63		1.48	
46–51	5.06		1.61	
52–60	5.74		1.83	
61–70	6.52		2.07	
71–90	7.72		2.46	
91–120	9.78		3.11	
121–180	13.38		4.26	
181–360	21.62		6.88	

There are two sets of numbers, one to be used when the calculations are based on diametral pitch, the other for use with circular pitch.

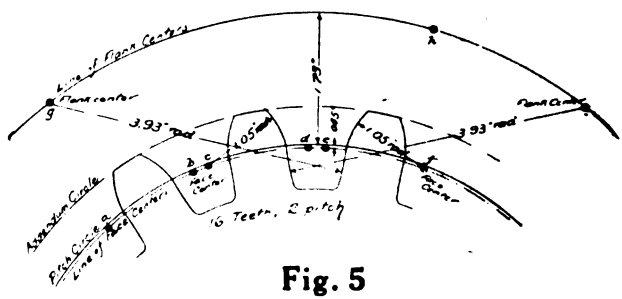


Fig. 5

The following example will make the application of the table clear:

It is required to lay out the tooth outline for a pinion having 16 teeth, 2 diametral pitch.

In order to make the required construction it will be necessary to know the following dimensions: diameter of the pitch circle; diameter of the addendum circle, or outside diameter;

diameter of the root circle; diameter of the base circle and the thickness of the tooth.

$$\text{Dia. of pitch circle} = \frac{\text{No. of teeth}}{\text{Pitch}} = \frac{16}{2} = 8''.$$

$$\text{Outside diameter} = \frac{\text{No. of teeth} + 2}{\text{Pitch}} = \frac{18}{2} = 9''.$$

Root diameter = Outside diameter − whole depth of tooth × 2 $= 9 - \frac{2 \times 2.157}{2} = 6.843''$.

Diameter of base circle = Pitch diameter × $\frac{58}{60} = \frac{8 \times 58}{60} = 7.733''$.

First draw the pitch, addendum, root and base circles, as shown in Fig. 4. Then space the pitch circle into the required number of divisions, in this case 16. Bisect these divisions, thus locating the pitch points *a*, *b*, *c*, *d*, etc.

From the table take the face radius corresponding to the number of teeth in the gear, and divide it by the pitch. In this case we would have $\frac{2.92}{2} = 1.46''$. Set the dividers to this distance and from the points *A*, *B*, *C*, *D*, etc., draw in the face curves from the pitch line to the addendum. In the same manner get the flank radius, which in this case would be $\frac{1.46}{2} = .73''$, and with the dividers set to this distance, from the points *E*, *G*, *H*, *I*, etc., on the base circle, draw in the flank curves from the pitch line to the base circle. The balance of the tooth outline is formed by drawing straight radial lines from the base line to the

root line, joining these lines by a filet having a radius equal to the clearance.

The template used in forming the tool is made the same shape as the space between the teeth. If care is used in the laying out a satisfactory gear will be produced.

If the teeth are to be of the cycloidal form, they will be laid out in the following manner, using the table headed "Cycloidal Odontograph":

CYCLOIDAL ODONTOGRAPH.

Number of Teeth in the Gear.		For One Diametral Pitch. For any other pitch divide by that pitch.				For One Inch Circular Pitch. For any other pitch multiply by that pitch.			
		Faces.		Flanks.		Faces.		Flanks.	
Exact.	Intervals.	Rad.	Dis.	Rad.	Dis.	Rad.	Dis.	Rad.	Dis.
10	10	1.99	.02	- 8.00	4.00	.62	.01	-2.55	1.27
11	11	2.00	.04	-11.05	6.50	.63	.01	-3.34	2.07
12	12	2.01	.06	∞	∞	.64	.02	∞	∞
13½	13–14	2.04	.07	15.10	9.43	.65	.02	4.80	3.00
15½	15–16	2.10	.09	7.86	3.46	.67	.03	2.50	1.10
17½	17–18	2.14	.11	6.13	2.20	.68	.04	1.95	.70
20	19–21	2.20	.13	5.12	1.57	.70	.04	1.63	.50
23	22–24	2.26	.15	4.50	1.13	.72	.05	1.43	.36
27	25–29	2.33	.16	4.10	.96	.74	.05	1.30	.29
33	30–36	2.40	.19	3.80	.72	.76	.06	1.20	.23
42	37–48	2.48	.22	3.52	.63	.79	.07	1.12	.20
58	49–72	2.60	.25	3.33	.54	.83	.08	1.06	.17
97	73–144	2.83	.28	3.14	.44	.90	.09	1.00	.14
290	145–300	2.92	.31	3.00	.38	.93	.10	.95	.12
∞	Rack	2.96	.34	2.96	.34	.94	.11	.94	.11

This form of tooth is laid out by arcs struck from two circles, one lying outside the addendum circle called the line of flank centers, the other lying inside the pitch circle called the line of face centers. See Fig. 5. The addendum, pitch and root circles are laid out as in the previous case, and the pitch points of the teeth

located. Then the line of flank centers is drawn at the tabular distance from the pitch line, in this case $\frac{3.46}{2}$ = 1.73″. Set the dividers to the flank radius, in this case $\frac{7.86}{2}$ = 3.93″, and from the centers *g*, *h*, *i*, etc., on the line of flank centers, draw the flank curves from the pitch line to the root line, joining the flank to the root with a fillet as in the previous case. The line of face centers is drawn inside the pitch line at the tabular distance, in this case $\frac{.09}{2}$ = .045″.

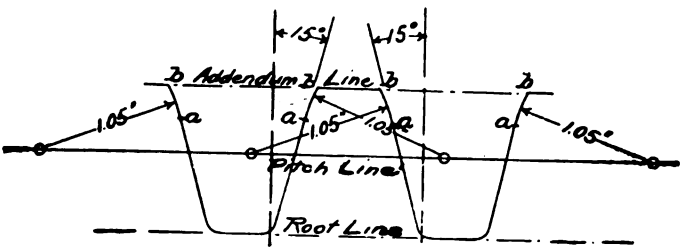


Fig. 6

Set the dividers to the face radius, in this case $\frac{2.10}{2}$ = 1.05″, and draw in the face curves from the pitch line to the addendum line, from centers *a*, *b*, *c*, etc., on the line of face centers.

The involute rack tooth is laid out as shown in Fig. 6. The sides or flanks of the tooth are drawn as straight lines, inclined to a line perpendicular to the rack face at an angle of 15°. The outer half of the tooth face from *a* to *b* is drawn from a center on the pitch line with a radius equal to $\frac{2.10}{\text{Pitch}}$, or .67 × circular pitch.

Before the machinist can do much toward

making bevel gear calculations it will be necessary for him to understand the application of the following trigonometric functions: sine, cosine, tangent and cotangent. These functions are all based on the proposition that *in all right-angled triangles, having the same acute angle, the sides have to each other the same ratios, and are proportional to the radii of the arcs enclosing the angles.* Fig. 7 shows an arc *c*, *e*, *f*, drawn from the center *a*. The angle included

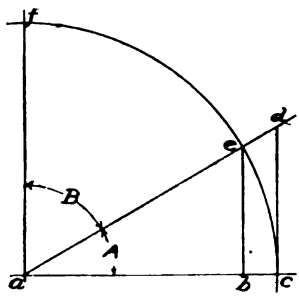


Fig. 7

between lines *a*, *f* and *a*, *c* is 90°. Line *a*, *e*, *d* divides the 90° angle into two angles *A* and *B*. The line *a*, *b* is the cosine of angle *A*, and the sine of angle *B*. Line *b*, *e* is the sine of angle *A*, and the cosine of angle *B*. Line *c*, *d* is the tangent of angle *A*, and the cotangent of angle *B*. A table of natural trigonometric functions contains the values of these lines for all angles from 0° to 90°, figured for a radius of the arc enclosing the angle equal to 1. If the radius is 2, the values of the functions would be

doubled, and so on. Hence, when the sine, cosine, tangent or cotangent is given for an angle in a circle whose radius is greater or less than 1, its value must be found for a circle whose radius is 1, before the tables can be used.

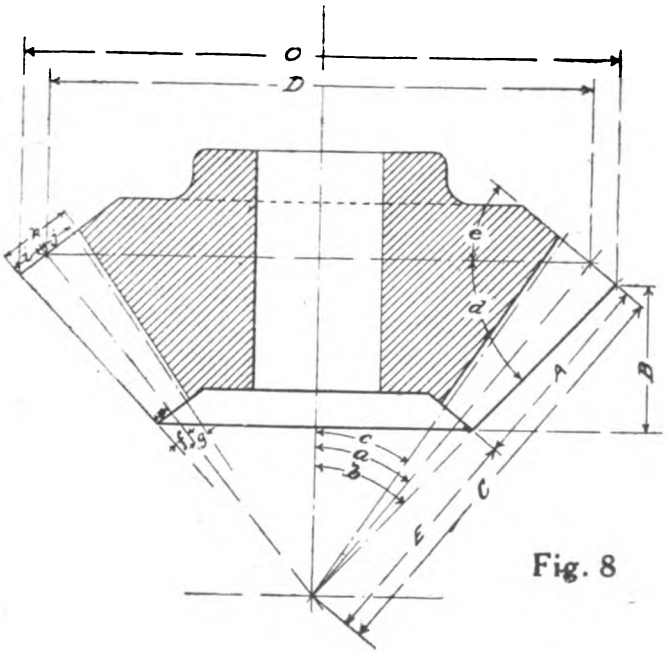


Fig. 8

In the majority of the tables published the angles run from 0° to 45° at the heads of the columns and are read downward, while angles from 45° to 90° are read from the bottom upward, using the extreme right hand column to find the minutes.

In bevel gears the relations between the pitch diameters, pitch, numbers of teeth, and velocity ratios are the same as for spur gears, remembering that the diameter of a bevel gear is the diameter *D* of the base of the pitch cone, Fig. 8.

Referring to Fig. 8, let

P = diametral pitch
D = pitch diameter
O = outside diameter
N = number of teeth
n = number of teeth in mating gear
A = length of tooth measured on the face of the gear
B = length of tooth measured parallel to center line of gear
C = apex distance
E = apex distance less length of tooth A.
a = center angle
b = face angle
c = Cutting angle
d = complement of face angle
e = edge angle = center angle
f and g = increment angles
i = addendum at large end of tooth
o = addendum at small end of tooth
k = whole depth of tooth at large end
l = whole depth of tooth at small end
m = chordal thickness of tooth at large end
n = chordal thickness of tooth at small end

then the following formulas will apply.

12. $P = \frac{N + \cos a,}{O}$ or $\frac{D}{P}$.

13. $D = \frac{N}{P}$.

14. $O = D + \frac{2 \times \cos a}{P}$.

15. $N = D \times P$.

16. $B = A \times \cos b$.

17. $C = \frac{N}{2 \times P \times \sin a}$.

18. $E = C - A$.

19. $\text{Tan } a = \frac{N}{n}$.

20. $\text{Tan } f = \frac{2 \times \sin a}{N}$.

21. $b = a + f$.

22. $c = a - f$.

23. $d = 90° - b$.

24. $e = a$.

25. $i = \frac{1}{P}$.

26. $o = \frac{E}{P \times C}$.

27. $k = \frac{2}{P} + \frac{1}{8 \times P}$.

28. $l = 2 \times o + \frac{1}{8P}$.

29. $m = \sin \frac{90°}{N} \times D$.

30. $n = \frac{E \times m}{C}$.

31. Number of teeth for which to select cutter $= \frac{N}{\cos a}$.

In order for the machinist to intelligently cut bevel gears it will be necessary for him to know the pitch; number of teeth; the outside diameter of the blank; the correct face, edge and cutting angles; the depth of the tooth at each end; the thickness of the tooth at the pitch line at each end; the height of the addendum at each end, and how to select a cutter of correct form and thickness.

For an example we will assume that it is required to replace one of a pair of bevel gears. The outside diameter of the broken gear measures, as near as can be determined, $5\frac{7}{8}$ inches, and has 16 teeth, 2 inches long. The mating gear has 20 teeth.

Using formula 19, the center angle will first be determined.

Tan $a = \frac{N}{n} = \frac{16}{20} = 0.8$, which is the tangent of the angle of 38° 40′.

By formula 12, the pitch $P = \frac{N + \cos a}{O} = \frac{16 + .78079}{5.875} = 2.8$, hence we may assume that the diametral pitch is 3.

By formula 13, $D = \frac{N}{P} = \frac{16}{3} = 5.333''$.

By formula 14, $O = D + \frac{2 \cos a}{P} = 5.333 + \frac{2 \times .78079}{3} = 5.85''$.

By formula 20, $\text{Tan } f = \frac{2 \sin a}{N} = \frac{2 \times .62479}{16} = .07809$, which is the tangent of the angle of 4° 28′.

By formulas 21 and 22, the face angle $b = a + f = 38°\ 40' + 4°\ 28' = 43°\ 8'$, and the cutting angle $c = a - f = 38°\ 40' - 4°\ 28' = 34°\ 12'$.

By formula 16, $B = A \cos b = 2 \times .72976 = 1.46''$.

By formula 23, $d = 90° - b = 90° - 43°\ 8' = 46°\ 52'$.

By formula 24, $e = a = 38°\ 40'$.

By formula 29, $m = \sin \frac{90°}{N} \times D. \frac{90°}{16} = 5°\ 37'$, and sin 5° 37′ = .10077; $.10077 \times 5.33 = .522''$.

By formula 17, $C = \frac{N}{2P \sin a} = \frac{16}{2 \times 3 \times .62479} = 4.268''$.

By formula 18, $E = C - A = 4.268 - 2 = 2.268''$.

By formula 27, $k = 2/P + \frac{1}{8}P = \frac{2}{3} + \frac{1}{24} = \frac{17}{24}''$.

By formula 25, $i = 1/P = \frac{1}{3}''$.

By formula 26, $o = \frac{E}{P\,C} = 2.268/3 \times 4.268 = .177''$.

By formula 28, $l = 20 + 1/8P = .354 + 1/24 = .396''$.

By formula 30, $n = Em/C = 2.268 \times .522/4.268 = .277''$.

By formula 31, the number of teeth for which to select the cutter = N / cos a = 16 / .78079 = 20.

Fig. 9 shows a gear laid out from the foregoing calculated dimensions, and is an example of the drawing that would be furnished.

In turning the blank the first operation would, of course, be to bore the hole, after which the

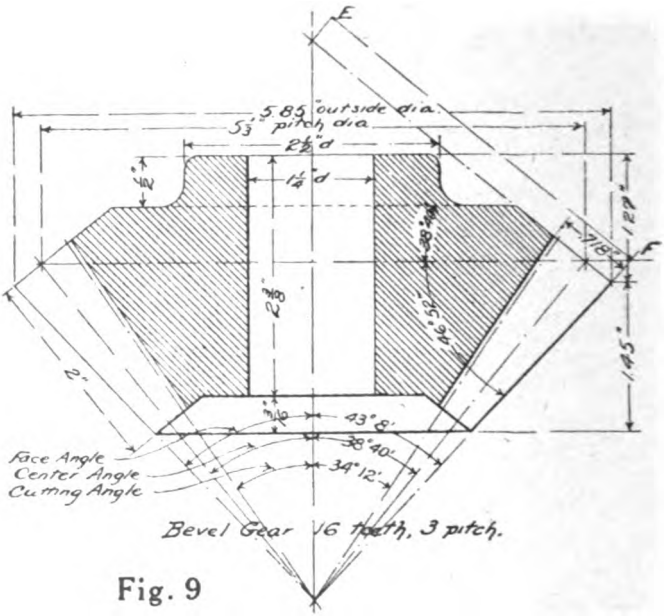


Fig. 9

gear would be mounted on an arbor and the blank turned to the outside diameter. Then the face angle would be turned by setting the compound rest to the correct angle, in this case 46° 52′. Next, the back angle, or edge angle, is turned, setting the compound rest, in this case

to 38° 40′, removing sufficient stock to bring the surface up to an edge with the face of the gear. At this setting of the rest, the inner ends of the teeth are finished, making the length of the tooth correct. The blank should be carefully checked over with a reliable protractor, and if correct it is ready to have the teeth cut.

As the teeth of bevel gears are tapered, being thicker at the outside end than at the inside end, it follows that the width of the spaces between the teeth is also tapered, so that a cutter wide enough to cut a correct space at the back of the teeth would cut too wide a space at the inside end. For this reason the ordinary cutters made for cutting spur gears should never be used for cutting bevel gears. Special cutters of the involute form are made for this purpose, being thinner than the standard spur gear cutters. These cutters are numbered from 1 to 8, and cover the same range of teeth as the standard cutters. For the same reason the bevel gear cutter cannot be selected for the number of teeth in the gear, but must be selected for the number of teeth given by formula 31. When a drawing of the gear is at hand the number of teeth for which to select the cutter may be determined as follows (see Fig. 9).

Measure the slant height of the back cone from E to F, double this and multiply by the diametral pitch. The result will be the number of teeth for which to select the cutter. In the gear given, the slant height measures $3\frac{3}{4}''$. $3\frac{3}{4} \times 2 \times 3 = 22\frac{1}{2}$, hence a No. 5 cutter would be used.

After selecting the cutter it is placed on its arbor, and the gear blank is placed in the machine. Before placing the blank in position the index head should be swiveled to the cutting angle, measured from the center line of the gear, in this case 34° 12′. The cutter and index center should be brought into alignment by setting the index center in line with the center line scribed on the tops of the cutter teeth. After setting the index head to divide for the required number of teeth, all is in readiness to make the trial cuts.

First, scribe a line on the back edge of the blank showing the depth of the teeth at this point. This may be done by using a "depth of gear tooth gauge" of the correct pitch (Fig. 10), or by using hermaphrodite calipers set to the calculated depth, as per formula 27.

Three or four spaces should be cut to the depth marked on the blank. The teeth cut will be too thick, especially at the large end. In order to cut them to the correct thickness the cutter must be set "off center" by moving the saddle toward the machine, measuring the amount of the set over by the dial on the cross feed screw. The exact amount of this offset cannot be determined exactly, but for the first trial it should be equal to about $\frac{1}{10}$ the thickness of the tooth at the large end. In this case the thickness of the tooth at the large end is .522 inch, and $\frac{1}{10}$ of this = .052 inch, hence the saddle would be moved .052 inch. It should be clamped firmly in this position. The gear blank

should now be rolled toward the cutter by means of the index handle, until the cutter will just enter the space at the *inner* end of the teeth. In doing this the adjustable sector should not be disturbed, but should be left in position to mark the hole which is correct for the center position of the blank.

The cutter will now trim the sides of the teeth, taking the heaviest cut at the large end of the teeth. Be sure the cutter trims the whole length of the tooth. The saddle should now be set off center in the opposite direction an amount equal to that in the first case, and the

Fig. 10

blank rolled toward the cutter the same number of holes the other side of the center hole, and the opposite sides of the teeth trimmed. The thickness of the teeth should be measured with a gear tooth caliper shown in Fig. 11. This caliper is for the purpose of accurately measuring the thickness of the tooth on the pitch line. The sliding jaw *a* moves upon the graduated bar *b*, and by means of a vernier gives readings to thousandths of an inch. The tongue *c* moves at right angles with the jaws and is graduated in the same manner. The tongue *c* is set to the height of the addendum and the points of the jaws will come exactly on the pitch line. In cases where the pitch is coarse and the diameter

of the gear small, if the tongue *c* is set to the calculated height of the addendum, the points of the caliper jaws will not come exactly on the pitch line, owing to the curvature of the pitch line. In such cases it will be necessary to make a correction for the height *c* of the arc *a* above

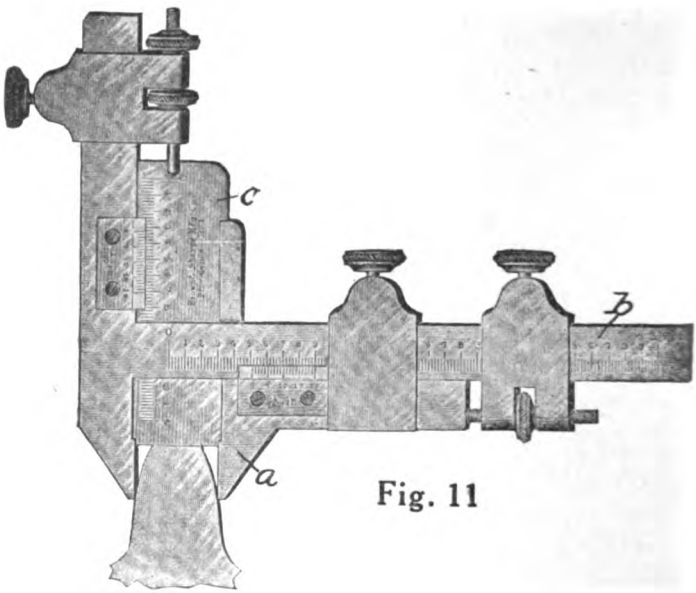


Fig. 11

the chord *b*, shown in Fig. 12. To find this height *c*, *divide* 90° *by the number of teeth, ascertain the cosine of the quotient, subtract it from* 1.0000, *and multiply the remainder by the pitch radius, or one-half the pitch diameter.* This amount added to the addendum is the correct height *o*, for which the tongue *c* must be set.

If the large end of the tooth is still too thick, it indicates that the cross slide was not off set enough from the center position, in which case another trial cut must be taken on each side of the tooth with a somewhat greater off set of the saddle. These operations should be continued until the teeth are the correct thickness at the large end. If the teeth are too thick at the small end it indicates that the blank was not rolled sufficiently toward the cutter, in which case the off set of the saddle should be less and the blank

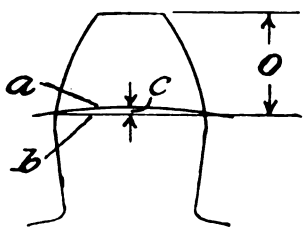


Fig. 12

rolled more, until the setting is such that both ends of the teeth will be cut the correct thickness.

Having thus determined the amount of the off set and the angle through which to roll the blank, the remaining teeth may be cut. If the pitch is fine this may be done by taking two cuts through each space, first taking a cut on one side of all the teeth, then adjusting the machine and blank and cutting the other sides. If the pitch is coarse, three cuts should be taken, a center cut first and then the two trimming cuts.

On gears having less than 30 teeth it will generally be found necessary to file the sides of the teeth above the pitch line at the small end, as the cutter will not round them off sufficiently. The teeth may be rounded off at the small end by slightly increasing the cutting angle, thus cutting the teeth a little deeper at the small end, but care must be exercised or the teeth will be cut too thin at the small end.

In making the cross slide and index center adjustments, the final movements should always be made in the same direction to avoid errors from any looseness in the parts. Thus, if the first off set was made by moving the cross slide toward the machine, when the off set is made in the opposite direction the cross slide should be moved enough further than the required amount so that the final movement will be toward the machine, as in the first instance.

CHAPTER XXIV.

ERECTING SHOP WORK—LAYING OUT BOILER WORK.

The locomotive boiler is made up of a number of sheets which are generally quite irregular in shape. These sheets have various holes in them for rivets, brace connections, boiler fittings, etc., and the location of these holes, as well as the shape of the sheets, must be laid out on the plate while it is flat. The boiler drawings generally show the sheets in position, and from these drawings the boiler maker must lay out his work. In some shops the development of the sheets is done in the drawing room and cards furnished which show the shape of the sheets and the correct location of all holes.

The operation by which the surface of an object is laid out is called the development of the surface, and is governed by the principles of projection. This class of work may best be illustrated by starting with some simple problems and gradually working up to the more difficult ones connected with boiler work.

The first problem will be the development of the surface of the cylinder shown in Fig. 1. Divide the circumference of the cylinder into any convenient number of *equal* parts, in this case twelve, and from the points of division draw lines 1–1, 2–2, 3–3, 4–4, etc., on the surface

of the cylinder, parallel to the cylinder axis. Now, if the cylinder be cut along any one of these lines and be rolled out into a flat plate,

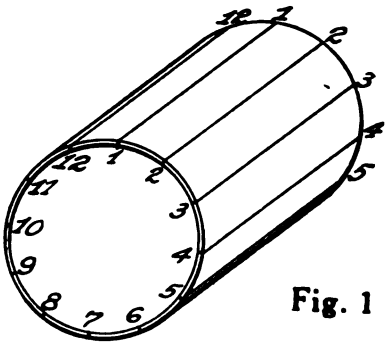
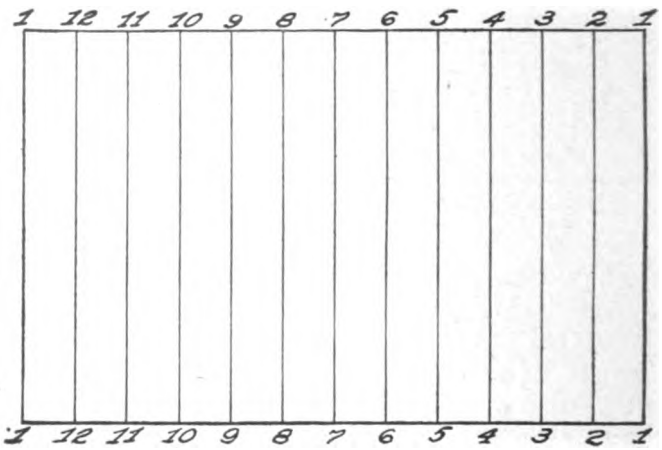


Fig. 1



the surface will be equal in length to the circumference of the cylinder, and will be as wide as the cylinder is long. It will contain all of

the parallel lines which were drawn upon the cylinder, the spaces between them being equal to the length of the equal spaces into which the circumference was divided (see the lower portion of Fig. 1). From this it will be readily seen that if the location of any hole or part with reference to the parallel lines is known, it may be easily laid down on the flat plate.*

In Fig. 2 is shown a cylinder 10 inches in diameter and 12 inches long. At the right

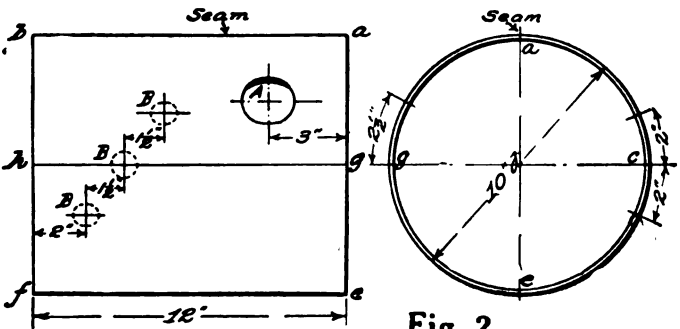


Fig. 2

hand end and on the left hand side is a hole *A*, 3 inches from the end and 2½ inches above the horizontal center line measured on the circumference. Near the left hand end and on the side away from the observer are located three holes *B*, *B*, *B*, 1½ inches apart in a horizontal direction, and 2 inches apart measured on the

* The development of any true cylinder is a surface having a length equal to the circumference of the cylinder and a width equal to the length of the cylinder.

circumference. The first, or lower hole, is 2 inches from the end of the cylinder.

The plate required for this will be 12 inches wide (the length of the cylinder) and 31.41 inches long (the circumference of a 10-inch circle). Lay off this plate as shown in Fig. 3, by dividing it into four equal spaces and drawing the lines *cd*, *ef* and *gh*, parallel with the edges *ab*, *a'b'* of the plate. As the work should be laid out on the outside of the plate, the line *aa'*

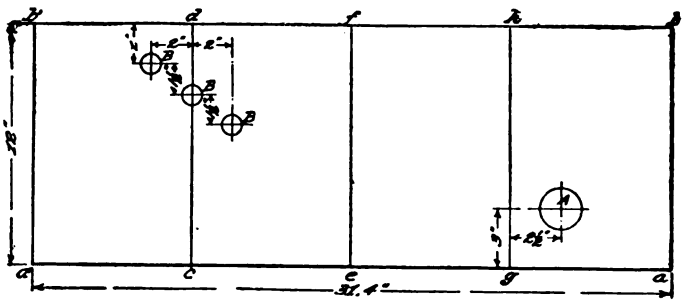


Fig. 3

will be the right hand end, and the line *bb'* will be the left hand end of Fig. 2. As we stand facing the cylinder, the hole *A* lies in the upper left hand quarter of the plate, as the joint is shown to be on top, and is 3 inches from the right hand end. It will therefore be laid off from the "quarter line" *gh*, as shown at *A*, Fig. 3. The three holes *B*, *B*, *B* will be laid off from the "quarter line" *cd* in the manner shown

Fig. 4(*a*) shows a cylinder having one end straight, or at right angles to the axis, the other end being cut off at an angle. To develop this sheet, divide the circumference of the

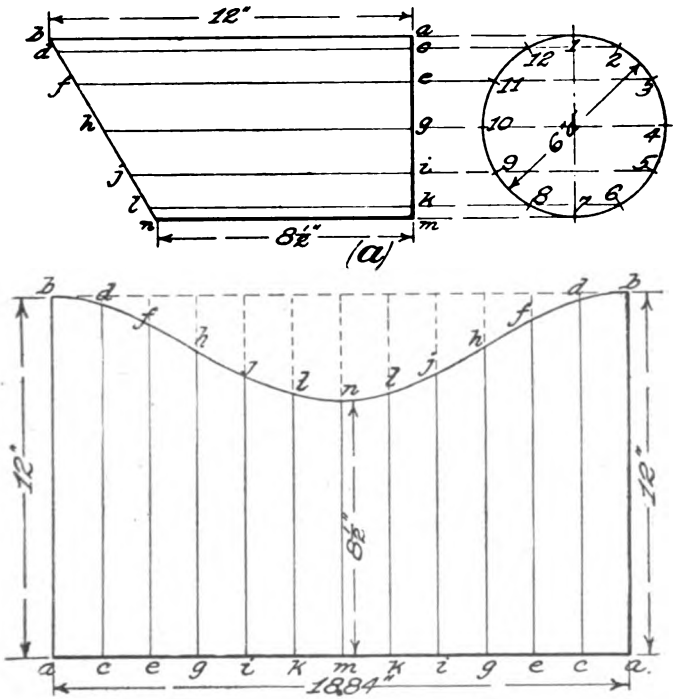


Fig. 4

cylinder into any convenient number of equal parts, in this case twelve, and from the points of division draw lines parallel to the axis of the cylinder, as *ab*, *cd*, *ef*, *gh*, *ij*, *kl*, *mn*, etc. If

the joint is assumed to be on top, the shape of the sheet will be as shown in Fig. 4(*b*), and will be determined as follows: Draw the line *aa'* having a length equal to the circumference of the cylinder, in this case 18.84 inches. Divide this line into the same number of equal parts as was the circumference, and from the points of division erect perpendicular lines *ab*, *cd*, *ef*, etc., of indefinite length. The lengths of the lines *ab* and *a'b'* will be equal to the length

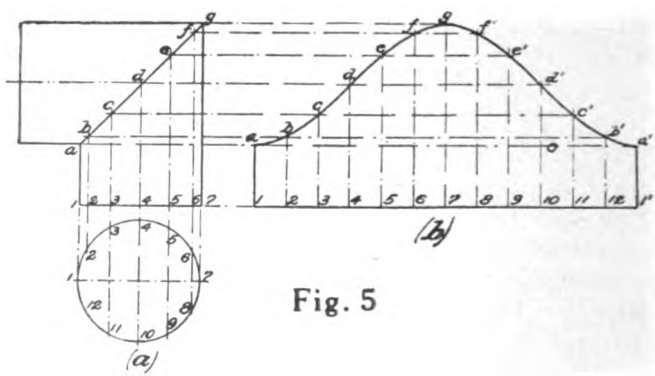


Fig. 5

of line *ab*, Fig. 4(*a*); the length of lines *cd* and *c'd'* will be equal to the length of line *cd*, Fig. 4(*a*); the length of lines *ef* and *e'f'* will be equal to the length of line *ef*, Fig. 4(*a*), and so on. A curve drawn through points *b*, *d*, *f*, *h*, *j*, *l*, *n*, *l'*, *j'*, *h'*, *f'*, *d'* and *b'* will give the shape of this edge of the sheet, and *a*, *b*, *n*, *b'*, *a'* will be the shape and size of the required sheet.

The right angled elbow shown in Fig. 5(*a*) is

formed by the intersection of two equal cylinders, their axis making an angle of 90°.*

To develop the sheet forming one-half of this elbow, proceed as follows: Divide the circumference of the cylinder into any convenient number of equal parts, and from the points of division draw lines parallel to the axis of the cylinder until they intersect the line of intersection at *a*, *b*, *c*, *d*, *e*, *f* and *g*. The shape of the sheet is then laid out as shown in Fig. 5(*b*), either as has just been described with reference to Fig. 4, or by projecting the points of intersection *a*, *b*, *c*, etc., as shown by the broken lines.

Fig. 5(*a*) shows two cylinders of different diameters intersecting at right angles. A common example of this is seen in the case of a boiler having a dome. In such cases the line of intersection becomes a curved one and must be determined before the sheets can be developed. Draw the lines *A*, *B*, *C*, *D*, *E*, *m*, *F*, *n*, outlining the required Tee. Draw a semicircle the size of the smaller cylinder from *E* to *F*; also, extend the lines *DC* and *AC*, as shown at *M* and *q*, and describe a quadrant from *C* as a center, with the same radius as the semicircle is struck by. Divide the semicircle into any convenient number of equal parts, in this case six, as *g*, *h*, *i*, *k*, *n* and *F*. Divide the quadrant into half the number of equal parts, as was the

* In this connection it may be said that the line of intersection *ag*, of two *equal* cylinders, no matter what the angle of intersection may be, will always be a straight line.

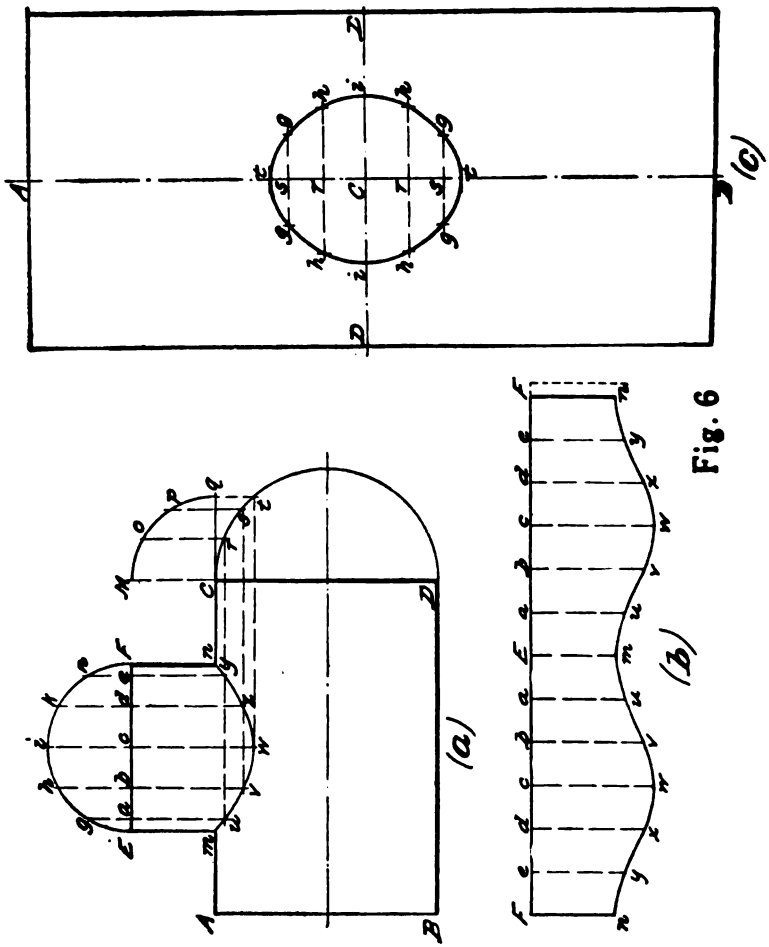


Fig. 6

semicircle, in this case three, as *o*, *p*, *q;* also, strike a semicircle from *C* to *D*, the size of the larger cylinder, and draw perpendiculars from *o*, *p* and *q* to cut the curve of the large cylinder at *r*, *s* and *t*. Draw lines from *r*, *s* and *t* parallel to *CA*, and draw perpendiculars from points *g*, *h*, *i*, *k*, *n* to intersect the horizontal lines *r*, *s*, *t* at *u*, *v*, *w*, *x*, *y*. These points of intersection will show the course of the curve of intersection. Draw the line *FF*, Fig. 6(*b*), making the length equal to the circumference of the small cylinder. Divide this line into *twice* as many equal parts as was the semicircle *EiF*, and from the points of division draw perpendicular lines. Take the lengths in Fig. 6(*a*), from *Fn*, *ey*, *dx*, *cw*, *bv*, *au*, *Em*, and transfer the same to the corresponding lines in Fig. 6(*b*), and draw a curve through these points *n*, *y*, *x*, *w*, etc., which will give the shape of the sheet necessary to form the smaller cylinder.*

To obtain the shape of the hole corresponding to the smaller cylinder, proceed as in Fig. 6(*c*). Draw the line *Ab* and bisect it at *C* with the line *DCD*. Take the distances from *C* to *r*, *C* to *s* and *C* to *t*, Fig. 6(*a*), and lay them off each side of *C*, Fig. 6(*c*), as shown at *r*, *s* and *t*, and through these points draw the lines *hh*, *gg*, etc., parallel with *DD*. Take the distance from *c* to *i*, Fig. 6(*a*), and mark off a corresponding distance on each side of *C*, as *i*, *i*, Fig. 6(*c*);

* The actual shape of the sheet will depend on where the joint is assumed to be located.

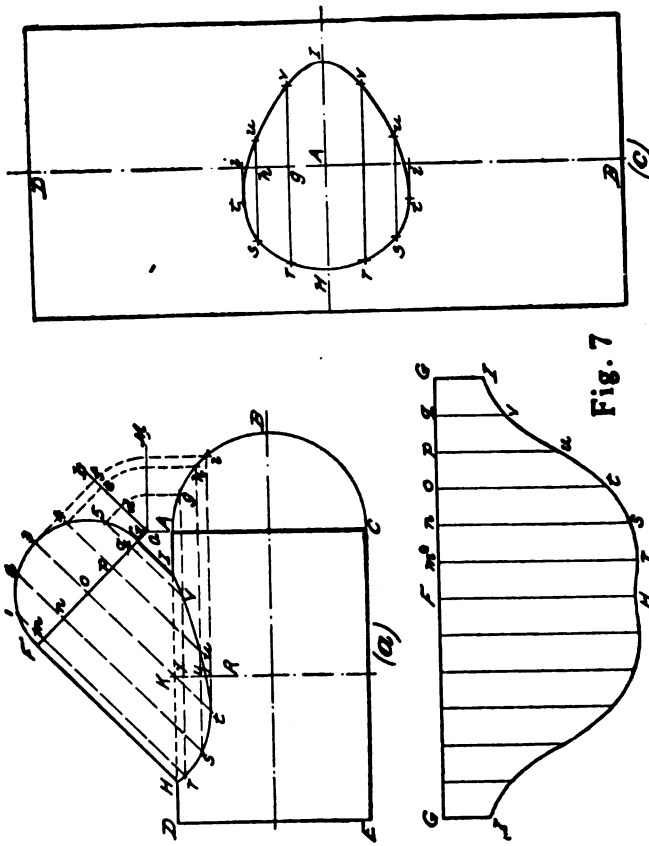


Fig. 7

also, the lengths *bh* and *ag*, Fig. 6(*a*), and transfer the same to Fig. 6(*c*), on each side of *r* to *h*, *h*, and each side of *s* to *g*, *g*; a curve drawn through these points will give the required shape of the hole.

Fig. 7(*a*) shows two cylinders intersecting at an oblique angle, or slanting direction. To determine the curve of intersection and the development of the sheets, proceed as follows:

Draw *DACE* to represent the larger cylinder, and *HFIG* the smaller one, connecting at any angle. Draw line GF at right angles to *HF*, and describe the semicircle from *F* to *G*, and divide it into any convenient number of equal parts, in this case six, as 1, 2, 3, etc. Draw lines through these points at right angles to *FG*. On line *AC* describe the semicircle *ABC*, representing the size of the larger cylinder, and extend the line *AC* to *a*, where it intersects line *FG*, extended. From *a* draw line *aM* parallel with *AD*, and from *a* draw line *ab* parallel with *FH*. Project points 3, 4 and 5 to line *ab*, as shown by drawing lines *3f*, *4e* and *5d* parallel with *FG*. With the dividers, from *a* as a center, project points *d*, *e* and *f* to line *aM*, as shown at d^1, e^1 and f^1. From points d^1, e^1, f^1 draw perpendicular lines cutting the circle of the larger cylinder at *g*, *h* and *i*, and from these points draw lines parallel with *AD*. Where these lines intersect the lines drawn through the smaller cylinder, as at *r*, *s*, *t*, *u*, *v*, will be the points through which the curve of intersection will be drawn. The shape of the sheet

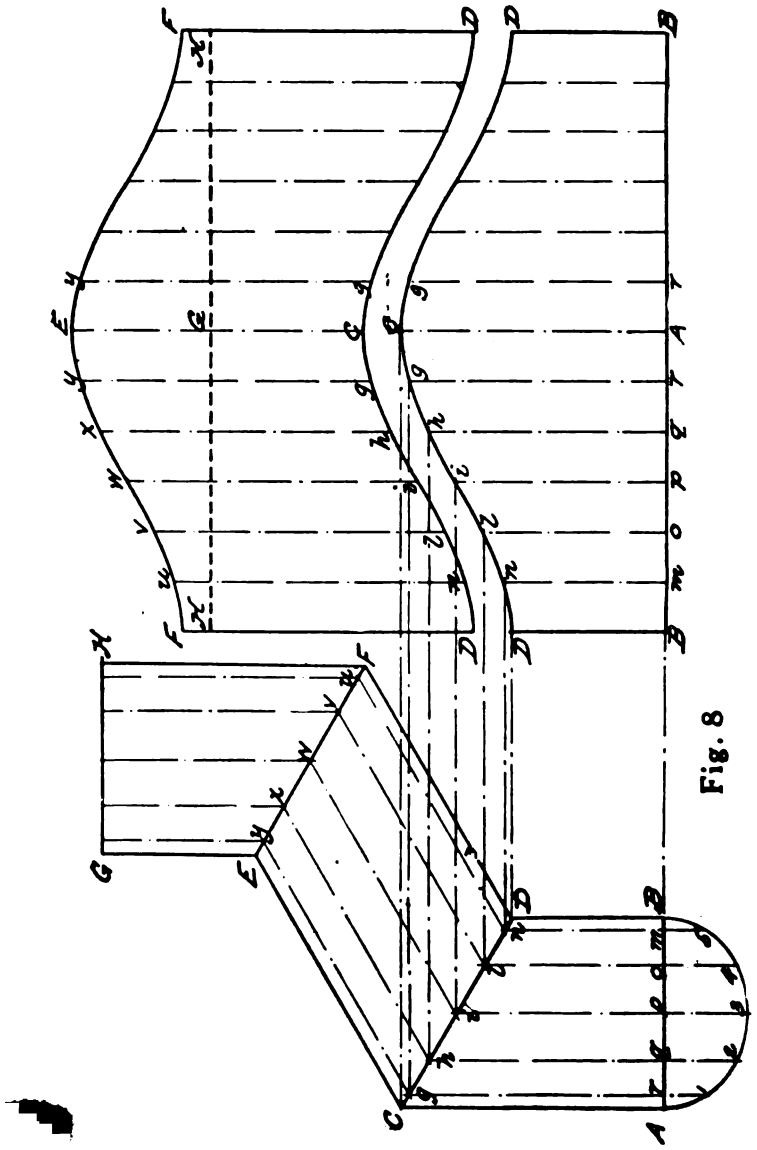


Fig. 8

forming the smaller cylinder is now determined in the same manner as was described with reference to Fig. 6(*b*), the lengths of lines *GI*, *gv*, *pu*, *ot*, *ns*, *mr*, *FH*, etc., Fig. 7(*b*), being the same as the lengths of the corresponding lettered lines in Fig. 7(*a*).

To obtain the shape of the hole in the larger cylinder draw *DB* and *HI*, Fig. 7(*c*), at right angles. Take the distance from *A* to *g*, *A* to *h* and *A* to *i*, Fig. 7(*a*), and mark off like distances on each side of *A* on the line *DB*, as *g*, *h* and *i*, Fig. 7(*c*), and through these points draw lines parallel to *HI*. Draw a perpendicular from point *K* to *R*, Fig. 7(*a*), and carry the length of *KH* and *KI*, Fig. 7(*a*), from *A* to *H* and *A* to *I*, Fig. 7(*c*); also, the distances *xr* and *xv*, Fig. 7(*a*), from *g* to *r* and *g* to *v*, Fig. 7(*c*); also, the distances *y* to *s*, and *y* to *u*, Fig. 7(*a*), from *h* to *s*, and *h* to *u*, Fig. 7(*c*). Take the distance from the line *KR* to *t*, Fig. 7(*a*), and mark off the same from line *i* to *t*, (Fig. 7(*c*), and the curve drawn through the points *H*, *r*, *s*, *t*, *u*, *v*, *I*, etc., will give the shape of the required hole.

Fig. 8 shows an angular elbow, the development of which is as follows: Draw *ACEGHFDB* according to the size of the pipe and the required angle. Draw the lines of intersection *CD* and *EF* from the points of the angles, showing where the joints are required. Extend the line *AB* indefinitely. Draw the semicircle the size of the cylinder, divide it into any convenient number of parts, as *1*, *2*, *3*, *4*, *5*, *B*, and take a corresponding number of parts from *B* to

A, and from A to B, as m, o, p, q, r, etc. Draw the perpendiculars BD, mn, ol, pi, qh, rg, AC, etc. Through the points *1*, *2*, *3*, etc., on the semicircle, draw the perpendiculars rg, qh, pi, etc. Either take the lengths of the lines, as AC, rg,

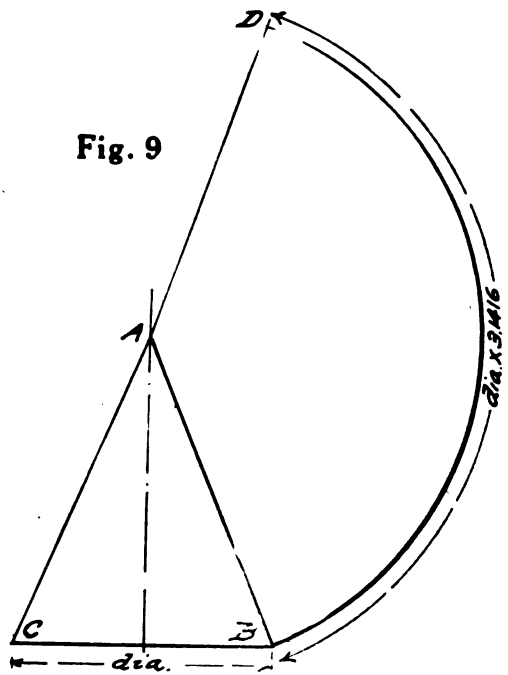


Fig. 9

qh, etc., and mark off the same lengths from A to C, r to g, q to h, etc., or draw lines parallel to AB from the points of intersection C, g, h, i, l, n and D to intersect the perpendiculars at C, g, h, i, l, n, D, and draw a curve through the

points thus found. This will give the shape of the sheet for the lower part of the elbow. The curve of the lower edge of the center portion will be the same, and the lengths of the lines *CE*, *gy*, *hx*, *iw*, *lr*, *nu*, *DF* in each figure will be equal. The shape of the upper portion

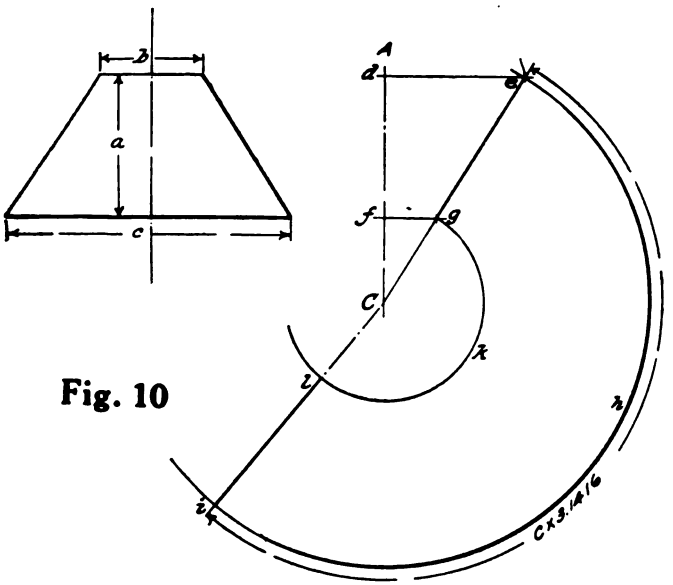


Fig. 10

of the elbow is that part of the center piece shown below the heavy dotted line *HGH*.

Fig. 9 shows the method of developing a sheet to form a cone. *ABC* is an elevation of the required cone. From the apex *A*, with *AB* as a radius, strike a curve *BD* of indefinite extent. From *B* lay off on the curve a distance

BD equal to the circumference of the base of the cone. Join *D* and *A* with a straight line and the figure *ABD* is the shape of the required sheet.

Fig. 10(*a*) shows a fustrum of a cone, a common example of which is seen in the hood for the stack connection on vertical boilers. To develop this sheet proceed as follows: (see Fig. 10(*b*). Draw the line *AC*, and take the upright depth required as *a*, and lay this off from *d* to *f*, and draw the lines *de* and *fg* at right angles with *AC*. On line *de* lay off the distance *e* equal to one-half of the large diameter *c*, and on line *fg* lay off the distance *g*, equal to one-half the small diameter *b*. Through points *e* and *g* draw a line cutting line *AC* in *C*. With *C* as a center, and with a radius *Ce*, strike a curve *ehi* of indefinite extent, and also from *C* as a center with *Cg* as a radius strike the curve *gkl*. From *e* make the curve *ehi* equal in length to the circumference of the large end of the cone and join *i* and *C* with a straight line. If the work has been accurately done the curve *gkl* will equal in length the circumference of the small end of the cone. The figure *gehilk* will be the shape of the required sheet.

Fig. 11 shows a cone cut by a plane which is not parallel with the base, and also shows the development of the resulting surface. Let *ACB* be the elevation of the cone cut by the plane *ab*. From the center *D* on the base line strike a semicircle, as shown, and divide it into any convenient number of equal parts, in this case

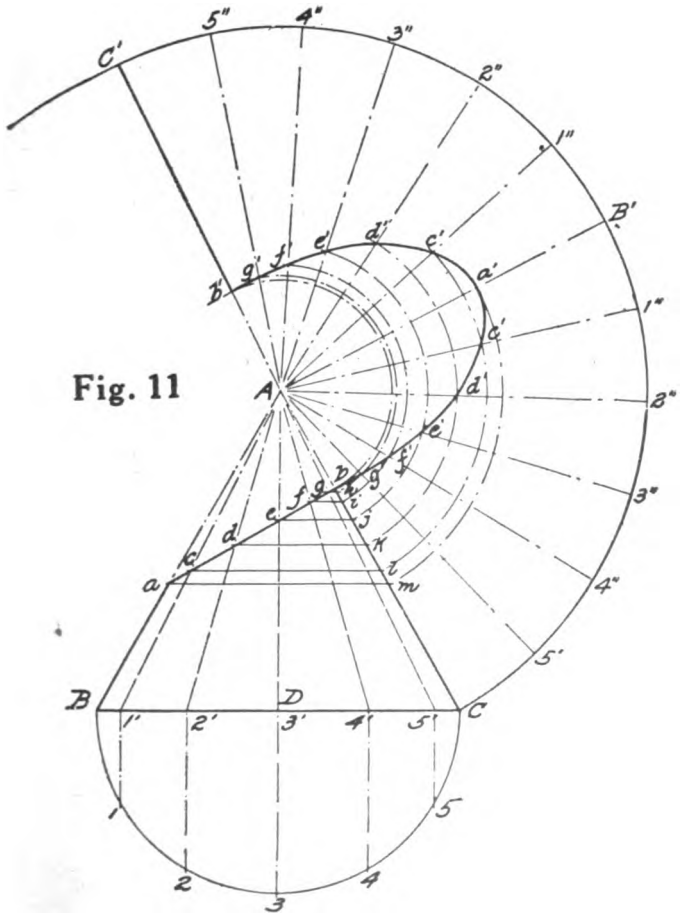
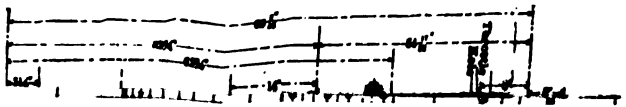


Fig. 11

six. From the points of division *1*, *2*, *3*, *4*, *5*. draw perpendicular lines to the base, thus projecting these points to the base line at 1^1, 2^1, 3^1, etc. Join these points with the apex *A*, of the cone, by the lines *A* 1^1, *A* 2^1, *A* 3^1, etc., cutting the plane *a b*, in *c*, *d*, *e*, *f* and *g*. From *A* as a center, with *A B*, or *A C* as a radius, draw the arc of a circle *C* C^1, making the length of this arc equal in length to the circumference of the base of the cone. Divide this arc into twice as many equal parts as was the semicircle, and from the points of division $5''$, $4''$, $3''$, $2''$, $1''$, etc., draw lines to the apex *A*, as shown. From the points *a*, *c*, *d*, *e*, *f*, *g*, and *b* draw lines parallel to the base, cutting the line *A C*, in *h*, *i*, *j*, *k*, *l* and *m*. With *A* as a center, and *h* as a radius, strike an arc, as shown, cutting the lines $5''$ *A* at g^1; with *A* as a center, and radius *A i*, strike an arc cutting lines $4''$ *A* at f^1; with *A* as a center, and radius *A j*, strike an arc cutting lines $3''$ *A*, at E^1, and so on. A curve drawn through these points will complete the development. The reason for projecting the points *c*, *d*, *e*, *f* and *g* to the line *A C* is that it would be entirely wrong to take the measurements from the lines 1^1 *A*, 2^1 *A*, 3^1 *A*, etc., because these lines, being on the surface of the cone, are inclined towards the observer, and so do not appear in their true length. Thus, the line *A e*, if measured on the surface of the cone, would evidently be the same length as the line *A j*, but in the figure it is much shorter. The line *A C* appears in the figure in its true length,



hence the points in the plane *a b* are projected to line *A C*, as shown, in order to get their true length.

As stated at the beginning of this chapter, the locomotive boiler is made up of a variety of sheets, some of which are regular in shape, while others are quite irregular. Taking the boiler shown in Figs. 12 and 13 for an example, it will be seen that the sheet forming the smoke box is a true cylinder and will be made of a rectangular sheet having a length equal to the neutral circumference, and a width equal to the length of the smoke box, plus the material necessary for the lap of the joint joining the boiler proper to the smoke box.

In this boiler the first course is also a true cylinder; the second course is the connection, or gusset course, and is an irregular shaped sheet; the third, or dome course, is also a true cylinder and the sheet would be a rectangle if it were not cut out along one edge where the throat sheet is connected to it.

In this boiler the outside fire box sheet is irregular in shape, due to the fact that the sides are tapered, and the two ends are formed with different radii. The back head is an irregular shaped sheet, as is also the throat sheet. The front flue sheet will be circular in shape; the back flue sheet will be irregular, as will also the dome sheet.

In figuring the length of a sheet, which when bent will form a cylinder, the neutral diameter, or diameter measured at the center of the sheet,

Fig. 13

is used. Thus, if the outside diameter of the smoke box is 66″, and the thickness of the sheet is ½″, the neutral diameter will be 66″ — ½″ = 65½″, and the length of the required sheet will be 65½″ × 3.1416 = 205.775″, or say 205¾″.

The front tube sheet shown in Fig. 14, before flanging, would be a circular plate having a diameter equal to the length of the neutral line. This neutral line is made up of the line *a*, the two arcs *b*, *b*, and the straight parts of the flange *c*, *c*. In addition to this diameter, sufficient material must be added to allow the edge of the sheet to be trued up after flanging. The dotted lines give the limits of the curved portion of the flange and are located on the plate for the guidance of the flanger. The sheet will come from the makers sheared approximately circular in shape. The center of the sheet should be found with a pair of trammels, by striking arcs at the center from several points along the outer edge. Through the center thus found two lines should be drawn at right angles to each other. From these lines all the various holes are laid out. The rivet holes in the flange cannot be laid out until after flanging.

The smoke box sheet of the boiler shown in Fig. 12 would be laid out in the following manner: Referring to the drawing, the width of the required sheet would be 22½″ + 41″ = 63½″. The inside diameter of the smoke box is 67$\frac{7}{16}$″ and the sheet is ½″ thick, hence the neutral

diameter will be $67\frac{15}{16}$", and the circumference will be 213.43". To make this smoke box will therefore require a sheet somewhat larger than $63\frac{1}{2}$" by 213.43".

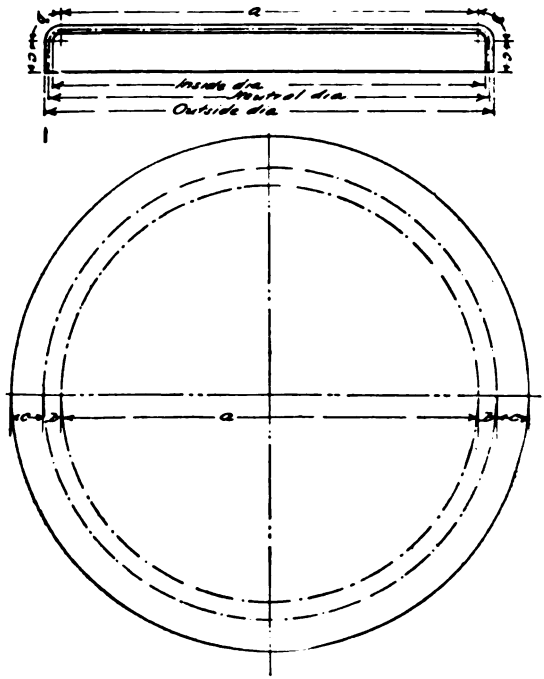


Fig. 14

Draw a line along the lower edge of the sheet from one end to the other, allowing about $\frac{1}{8}$" for planing. From this line measure off the width of the sheet, $63\frac{1}{2}$", at each end, and

through the points thus found draw a line along the top edge of the sheet. Draw a line close to one end of the sheet, allowing sufficient metal for planing, and from this line measure off the length of the sheet, 213.43″, and draw a line through this point square with bottom line. The sheet should now be quartered, and the longitudinal center line drawn, as well as the line defining the center of the cylinders. Generally all dimensions will be referred to the cylinder center line, and care must be taken not to measure them from the center line of the sheet. The front row of rivets is $1\frac{1}{8}$″ from the edge of the sheet, therefore a line will be drawn this distance from the front edge of the sheet. As there are 52 rivets in this seam, there will be 13 rivets in each quarter, and they will be laid off with the dividers spaced to give 13 divisions between each quarter line. The back seam will be laid off in exactly the same manner, except that it is a double riveted seam and has 60 rivets in each row, or 15 rivets in each quarter.

The balance of the work will be laid off from the center lines, and in this connection it should be said that generally all work is to be laid off on what will be the outside of the sheet.

The third course of this boiler is a fustrum of an oblique cone. This is generally the shape given to this sheet, but not always. There are several methods by which this sheet may be developed, but the one here given has the advantage that it will answer for any irregular

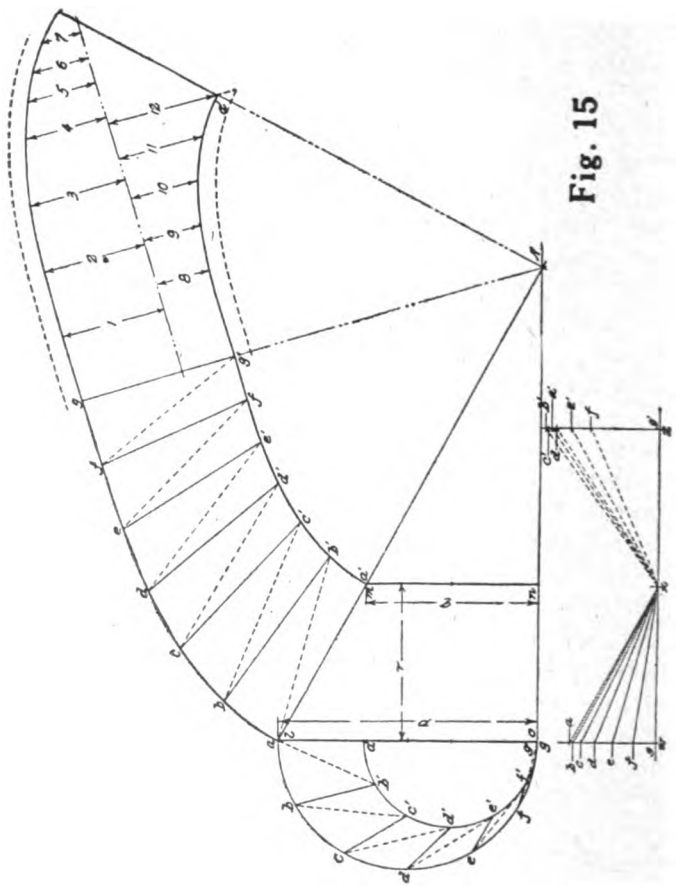


Fig. 15

shaped sheet, no matter what the form may be. Fig. 15 shows the method of developing this sheet. In this figure the bending lines only are shown, the dimension r being the length of the sheet less about 2″ more than twice the width of the joints.

To develop this sheet, proceed as follows: Draw $l\ m\ n\ o$, the shape of the sheet when bent, making $o\ l = p =$ the neutral diameter of the large end; $m\ n = q =$ the neutral diameter of the small end; $r =$ the length between the bending lines. On $o\ l$ draw the two semicircles $a\ d\ g$, representing the large diameter and $a^1\ d^1\ g^1$ representing the small diameter. Divide these semicircles into a convenient number of equal parts; the greater the number of these divisions the more accurate will be the results. Join the points b and b^1, c and c^1, d and d^1, e and e^1, f and f^1, by full lines, and join the points a and b^1, b and c^1, c and d^1, d and e^1, e and f^1, f and g^1, by dotted lines, as shown. Then make the construction shown at the bottom of the figure. Draw $a\ w$, at right angles to $w\ x$, and $b^1\ z$ at right angles to $z\ x$. Make wx, and zx, equal to r. From w lay off on line $w\ a$ distances $w\ a$, $w\ b$, $w\ c$, $w\ d$, $w\ e$, $w\ f$, respectively, equal in length to the full lines $a\ a^1$, $b\ b^1$, $c\ c^1$, $d\ d^1$, $e\ e^1$, $f\ f^1$. From z lay off on line $z\ b^1$ distances $z\ a^1$, $z\ b^1$, $z\ c^1$, $z\ d^1$, $z\ e^1$, $z\ f^1$, respectively, equal to the lengths of the dotted lines $a\ b^1$, $b\ c^1$, $c\ d^1$, $d\ e^1$, $e\ f^1$, $f\ g^1$.

Assume that the joint is to be on the top center line $a\ a^1$. From a as a center, with the

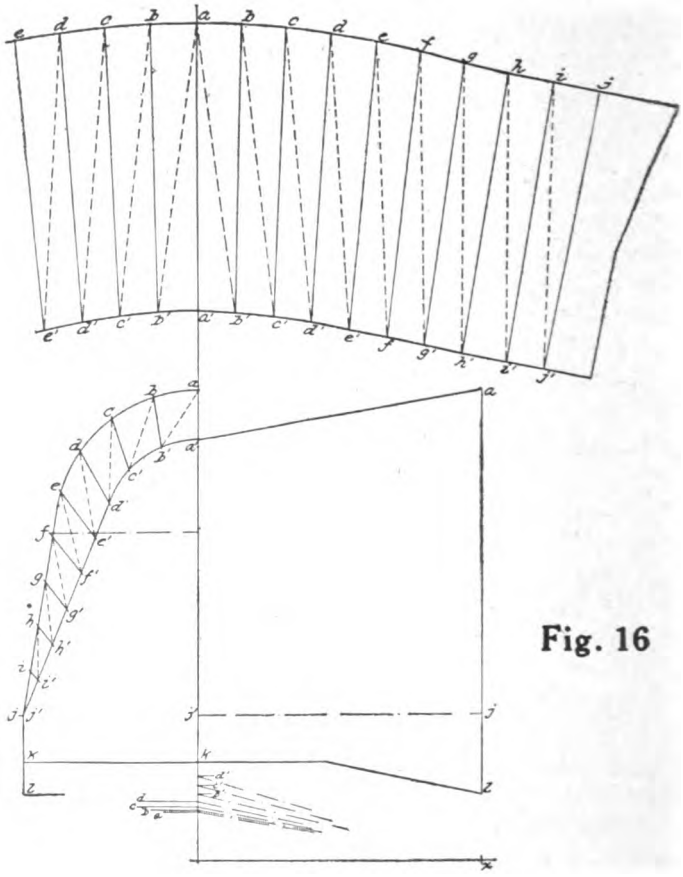


Fig. 16

dividers set to the length of line a^1 x, scribe a short arc, and from a^1, with the dividers set to the length of the arc a^1 b^1, scribe an arc intersecting the first one at b^1. From b^1, as a center, with the dividers set to the length of the line b x, scribe a short arc, and from a, with the dividers set to the length of arc a b, scribe an arc intersecting at b. From b, as a center, with the dividers set to the length of the line b^1 x, scribe a short arc, and from b^1, with the dividers set to the length of the arc b^1 c^1, scribe an arc intersecting at c^1. From c^1, as a center, with the dividers set to the length of the line c x, scribe a short arc, and from b, with the dividers set to the length of the arc b c, scribe an arc intersecting at c. Proceed in the same manner locating successively points d^1, d, e^1, e, f^1, f, g, g^1. The line g g^1 will be the center of the sheet and the other half will be the same shape. If line a a^1 be extended it will intersect line o n, extended, at A, which will be the apex of the cone of which the sheet forms the frustrum. If the work has been accurately done, a line drawn through the points g and g^1 will also pass through point A. A curve drawn through the points thus found will define the shape of the sheet, and the length of these curves should be equal to the respective neutral circumferences of the sheet. Generally this part of the work would be done in the drawing room, or by the boiler maker, to reduced scale. In such cases a reference line B B, would be laid down at right angles to the center line g g^1,

and dimensions as shown at *1*, *2*, *3*, *4*, etc., would be laid off for the purpose of transferring the shape to the plate. The dotted lines in the figure show the amount added beyond the bending lines for the joints, and as the length of these lines will be equal to the length of the bending lines, the edges at a and a^1 will be parallel with the center line $g\ g^1$.

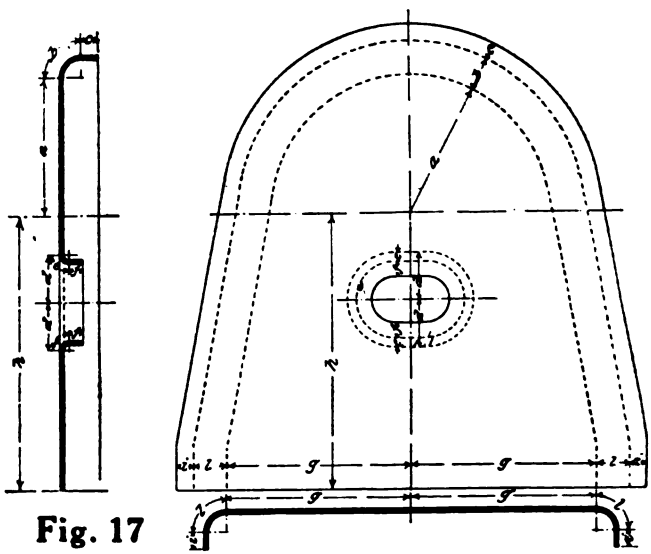


Fig. 17

Fig. 16 shows the application of the foregoing method of development to the outside firebox sheet of the boiler, shown in Figs. 12 and 13. This figure is distorted for the purpose of better showing the shape of the sheet. The method pursued is exactly the same as has just been

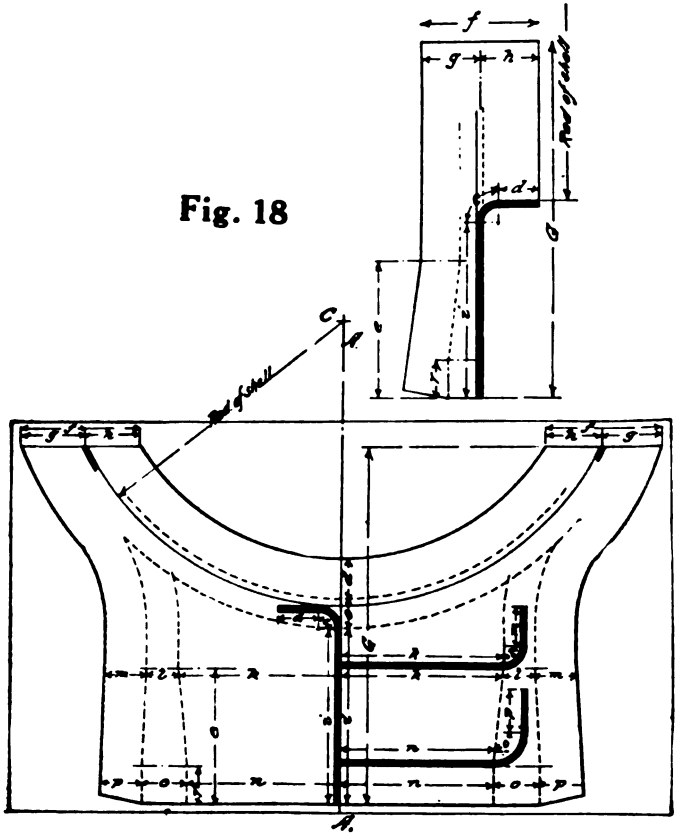
described, hence will not be repeated. It might, however, be well to call attention to the shape of this sheet below the line $j\ j^1$. From these points the sheet is flat, hence the edges would be at right angles with the line $j\ j^1$ in the upper figure.

Fig. 17 shows the development of the back head. The letters in the various figures refer to the same dimensions, and the method of development will be clear without further description.

Fig. 18 shows the development of a throat sheet. This is a difficult sheet to flange, and is also rather hard to lay out properly. The upper figure shows a section through the center of this sheet after it is flanged; the lower figure shows the shape of the sheet before flanging; the solid black lines on this figure show the shape of the sheet after flanging at the points where they are located. The letters on the various views refer to the same dimensions.

Draw the center line *A A*, in the center of the sheet, and then from the figures on the drawing locate the center of the boiler, as at *C*. From this center strike the inside radius of the sheet, as shown. From the bottom of the sheet lay off the distance *G*, and draw a line at right angles with the center line. This line will define the top of the sheet. After flanging, this portion of the sheet is a straight line, that portion marked *h* being turned forward, while the portion marked *g* is turned backward. Therefore, from the neutral line the distance *h*

Fig. 18



will be laid off toward the center of the sheet and the distance *g* laid off toward the outside of the sheet. From the bottom of the sheet lay off along the center line the length of the neutral line *i c d*. This will give a point on the center line through which an arc should be struck which will define this portion of the sheet.

The sheet at the bottom is flat for a distance *n*, each side of the center line, *o* is the length of the neutral line for the mud ring corner, and *p* is the width of the flat portion of the flange. These dimensions hold good for a distance *r* above the bottom line of the sheet. At a distance *e* above the bottom line the plate is flat for a distance *k*, each side of the center line; *l* is the length of the neutral line for the radius the corner is bent to at this point, and *m* is the length of the flat portion of the flange. The dotted lines show the limits of flanges. In flanging this sheet, the first operation is to turn back the flange marked *p*, *m* and *g*. Then the flange marked *h* and *d* is turned forward.

BOILER WASHING SYSTEM.

One of the many requirements now made by congress is the proper care of the locomotive boiler. The minimum requirements are that each boiler shall be washed at least once each month.

Several disadvantages have attended boiler washing: First, it consumed considerable time which might seriously interfere with transportation in busy times and, second, bad results often followed from the frequent cooling down and reheating of boilers, causing undue expansion and contraction, with the accompanying cracking of sheets and leaking of flues. With the hot water system of boiler washing these bad effects are reduced to a minimum as the time consumed is about one-half that of the former, and it is claimed that no bad effects will follow, as the washing and filling is done with hot water, thereby keeping the flues and sheets hot all the time.

Several different boiler washing apparatuses have been put on the market, and the one here described is known as the "National Boiler Washing System," of which Fig. 1 is a general outline view, and Fig. 2 is a view of the plant as it looks installed in a roundhouse.

Beginning with the locomotive in Fig. 1, it may be stated that the steam and water are blown out of the locomotive through the blow-off line 56, between the pits and through the main blow-out line, which extends around the entire roundhouse and then into the filter A. The steam and water then strike a baffle plate, where the steam is separated from the water, and rises from filter A, and passes through blow-out steam pipe No. 4 into open heater B. As the steam and water pass to filter A they open flop valve 34, by their pressure, which is connected to fresh water valve 31. This admits cold water to open heater B while the engine is being blown off. The steam entering the open heater B heats the cold water automatically admitted by the blow-off steam and water, and in sufficient quantity to refill the same boiler, which flows through pipe 38, to storage tank F, for filling water.

A thermostat, 43, which is placed in storage tank F, controls live steam valve 44, by opening it when the temperature in the tank is below any desired temperature, preferably 170 degrees Fahr. At this point the thermostat automatically operates and closes the live steam valve, thus maintaining the water at 170 degrees Fahr. for filling purposes. This valve is seldom opened, as the blow-off steam from the boilers generally maintains the proper temperature.

Float 39 and valve 42 are for the purpose of controlling the admission of fresh water to the filling water tank when the level of the water falls below a certain point. In this manner there is a minimum amount of water for filling purposes at all times.

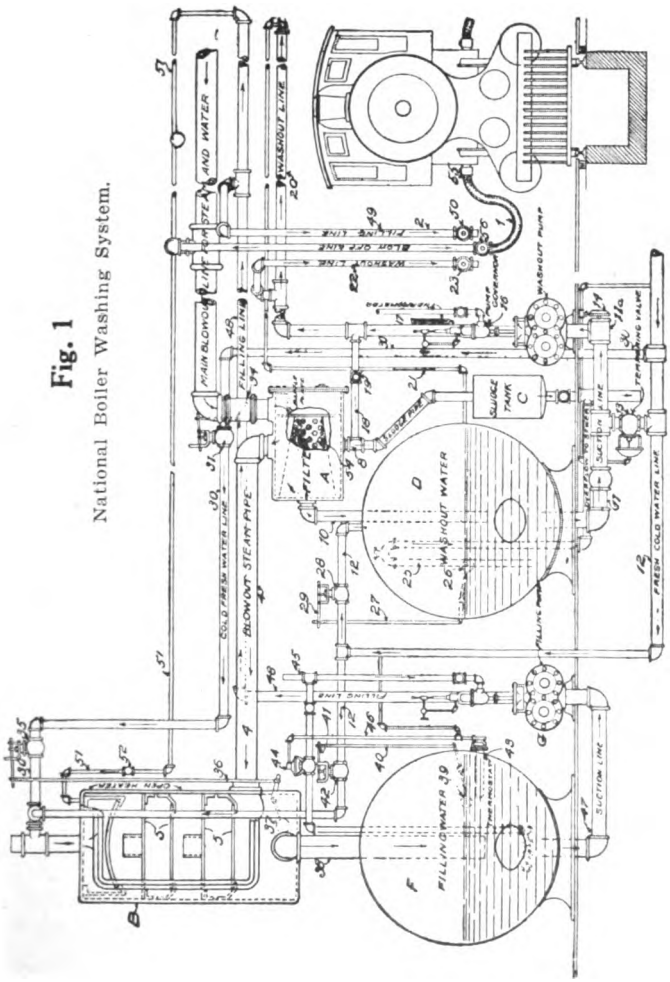


Fig. 1

National Boiler Washing System.

The hot water from the filling tank F is pumped by filling pump G, and discharged from filling line 48, which extends around the engine house, into filling line drop pipes 49, between pits. On the ends of the drop pipes are placed heavy pressure gate valves to which a hose can be connected for filling the boilers through blow-off cocks.

The water in filter A passes through the perforated cone-shaped filter plate 54, and filtering material into pipe 10, which leads into washout water reservoir D. Also leading from filter A is a sludge pipe which is connected with sludge tank C. All sludge and scale blown into filter A will drop into this tank, from which it can be washed into the sewer. By this means of purification and storage the greatest amount of waste heat blown out of the locomotive boilers is claimed to be saved.

The temperature of the water direct from the washout tank will ordinarily be about 185 degrees Fahr., but as washout water above 150 degrees Fahr. can not be safely handled, a cold water line No. 12 connected to hot water suction line No. 11, with a tempering valve No. 13 is used. This valve is actuated by a thermostat, 14, inserted in tee 11a, in suction line 11, which maintains a positive temperature of the washout water. The washout water is discharged from the washout pump through washout line 20, which extends around the engine house and through drop pipes 22, at the sides of the pits.

Circulating pipes extend from the ends of the washout and filling pipes back to the reservoirs. Through these pipes, 51 and 21, a constant circulation of washout and filling water is maintained.

For blowing out the boiler, connection is made from the blow-off cocks 55, to blow-off drop pipes 56. By this arrangement it is claimed that a boiler can be emptied in about thirty minutes. The storage capacity of the filling-water reservoir is about 10,000 gallons. The washout reservoir has a storage capacity of 8,500 gallons. The pumps are brass-fitted, duplex, and equipped with pump governors and lubricators. The washout pump has sufficient capacity to wash three boilers at one time and maintain about 90 pounds pressure. The filling pump has a capacity of 500 gallons per minute, running at 85 strokes per minute.

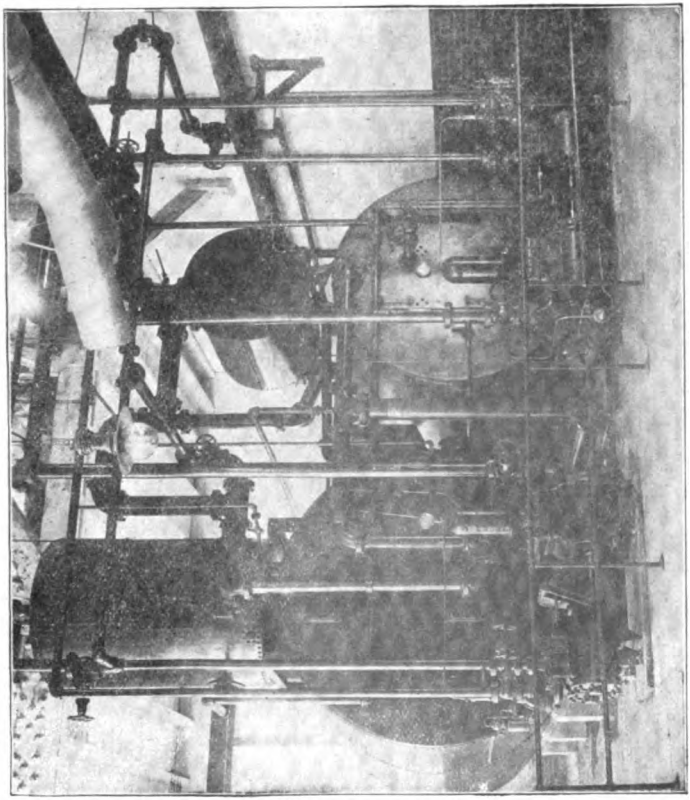


Fig. 2 National Boiler Washing Plant Installed.

MICROMETER BORING TOOL.

There have been many improvements in machine tools and implements used with the same during the last decade, each one aiming at an improvement in product or in a reduction of cost,

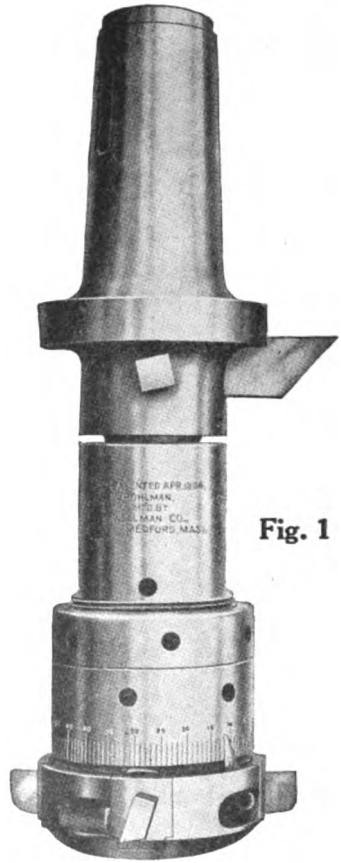


Fig. 1

or in both. A very notable one is the adjustable or expansion boring tool, known as the "Twentieth Century Boring Tool," which is finding its way into shops as a very useful article, espe-

cially as applied to the refitting of wheels to old axles. The expansion boring tools offer nearly the same opportunity that one has in a planer—of using several cutters in order to diminish the power required to remove a certain amount of metal. These tools which have a micrometer adjustment (see Figs. 1 and 3) make the roughing and finishing cuts in one operation.

Four cutting tools are used, and so arranged that but ¼-inch additional feed over the length of the hole to be bored is required for the finishing cut. By the micrometer adjustment the cutters may be set in or out accurately within .001 inch. In Fig. 2, A and B are the cutters. C is a vertical section of one of the cutter carriers, and D is a horizontal section. These carriers, as shown at C, have a projection on the top, the faces of which make an angle of 45 degrees with the top of the carrier. The outer, or right hand, surface of this projection bears on a corresponding beveled surface on the under side of the micrometer ring. The inner surface bears on a beveled surface in a sliding bar. There are four of these bars, one for each tool, and they are held in longitudinal slots in the tool body under the micrometer ring. This part of the body is not threaded, and the micrometer ring is free to slide up or down. However, these sliding bars extend beyond the tool body and are threaded to fit the inside of the micrometer ring. By turning this ring they will be raised or lowered, as desired. When they are raised the beveled surface is lifted from the corresponding surface on the cutter carriers, and when the micrometer ring is pressed down, it being loose on the body of the tool holder, the tools are forced by the beveled surface on the inside of the ring until they again bear on the beveled surfaces of the sliding bars. When the micrometer ring is turned the other way the sliding bars are lowered, causing them to bear on the inside of the projection of the tool carrier, which forces the tool out.

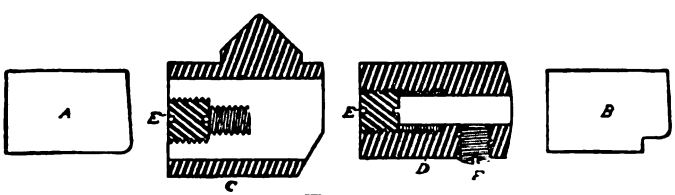


Fig. 2

The upper ring or set collar is threaded to the tool body and when the tools are once adjusted, it is screwed down against the micrometer ring and holds it in place. The threads on the sliding bars have a pitch of .125-inch. There are 125 micrometer grad-

uations, so that the movement of the ring by one graduation means the moving of the tool carrier .001-inch. The tool is held in the carriers by screws E and F, E being the adjusting screw and F

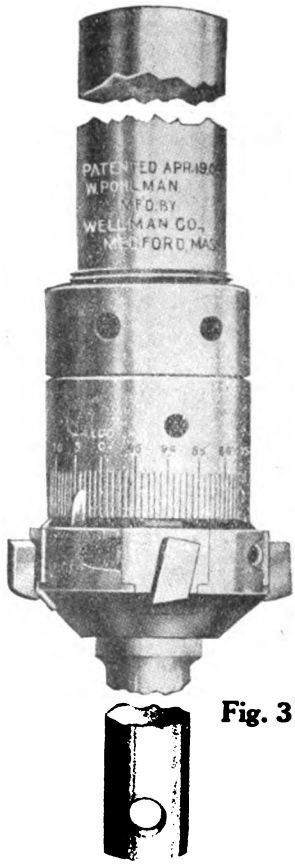


Fig. 3

the locking set screw. The cutters may be ground to any length, but when located in the cutter holders they must be equidistant from the center. The tool A shows the approximate shape of the

tools, and B shows the way in which the finishing tool is cut to follow the tool A. When adjusted for finishing this tool is allowed to project about 1-16-inch beyond A. As this tool revolves each cutter cuts to a depth of 1-16-inch, so that in one full revolution of the tool there has been removed ¼-inch of metal since each of the four cutters have made a cut of 1-16-inch.

When fitting car wheels to old axles, one sets the cutters approximately to the size, and then by the use of a micrometer-gauge on each succeeding wheel-seat the variation from that size is noted in thousandths and the corresponding change made in the cutters by the use of the micrometer ring on the tool.

These tools are made for use in any tool used for boring.

OXY-ACETYLENE WELDING AND CUTTING—THERMIT WELDING.

The oxy-acetylene method of welding while a process of uniting metals of the same and of different characters, conforms to neither welding nor soldering. It is not welding, because pressure is not needed. It is not soldering, because it is not necessary that there should be an intervening film of a different substance. It is perhaps nearer to welding, although it is not of such limited application.

The object of welding is to secure a union without destroying the form and condition of the pieces except at the junction. The high temperature required is supplied by the flame of the oxy-acetylene torch. Considering the rapid and tremendous losses due to the cooling effects of the surrounding air and the metal being treated, the temperature of the particles which actually are concerned in the flame itself must be enormous. To melt the surface of a metal whose fusion point is, say 2,500 degrees Fahr. it will be necessary to have a flame whose temperature is far in excess of this point, in order to get practical results.

The process employed in the Davis-Bournonville system of acetylene welding is to mingle acetylene and oxygen under pressure and then ignite the mixture at the exit of a suitable tip. Combustion is thus effected and high temperature attained. The oxy-acetylene torch is said to produce a temperature of 6,000 degrees Fahr. or more. The tip which is an important part is perforated along the axis. But this perforation is not uniform throughout. The oxygen, under pressure, enters at the rear end, but as the tubular hole is immediately contracted, it is checked. Passing through this contraction, the oxygen finds its way into an axial mixing chamber extending the whole remaining length of the tip. The acetylene, also under pressure, has likewise found its way into this mixing chamber by radial holes so dimensioned that the pressure of the oxygen is in excess of that of the acetylene.

If the flame which issues from the tip be examined when it is produced in such a way as to be most effective it will be found to be double; that is, there is a central core of rather diminutive

proportions enclosed in a large envelope. It is the inner portion which is the welding agent. The whole of the inner flame is not at the maximum heat, but only the outer end. Gases are not in the highest state of combustion, immediately they are mixed and ignited. A short interval of time is needed, which in the present case, is merely the time required to travel from the exit to a point 2/5 to 9/16 of an inch away. So that if the highest temperature attainable is desired this must be remembered.

The carbon and the hydrogen of the acetylene must be dissociated. The carbon must unite with part of the oxygen to form carbon monoxide. As there is a considerable forward velocity, the principal locus of both actions is at the outer extremity of the inner flame. During the interval between its dissociation from the hydrogen and its subsequent union with the oxygen, the carbon shines with a brilliant incandescence, giving rise to the resplendency of the inner flame. This is a very small space, as the oxygen almost instantly unites with the free carbon.

To carry out the process of obtaining the standard form of flame, proceed as follows: Ignite the torch when there is an excess of acetylene. There will be a dull white flame. As the oxygen is gradually increased, the flame becomes a more brilliant white, and diminishes in size. In fact, if the bluish envelope which forms is included, the flame is triple. Within are two distinct flames of unequal brightness. By increasing the supply of oxygen—or, by decreasing the supply of acetylene—these two inner flames may be made to grow together. When this takes place, the correct welding flame has been produced.

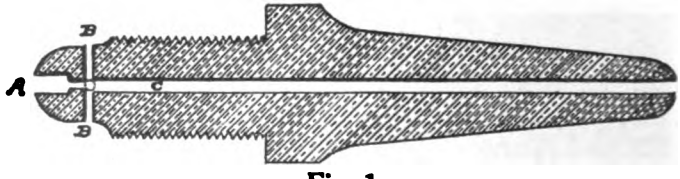


Fig. 1

Cross Section of Burner Tip.

The acetylene is under pressure as well as the oxygen and enters the tip, Fig. 1, through opening A. The acetylene joins the oxygen which comes in at right angles through four radial inlets, B, B. The oxygen has just passed through the point where its flow has been checked. This is, likewise, the case with the acetylene. As both gases expand in currents at right angles to each other, they are well mixed at once. Entire dependence, however, is not placed upon this initial mixing. The tip is considerably prolonged to afford a sufficient locus for its completion. It is important that the tip is so constructed that the oxygen enters back

of the acetylene. It will be seen that the oxygen drives the acetylene on. If other particles of acetylene are carried in because of the superior velocity of the oxygen, they are, nevertheless, brought into a position where other oxygen particles just entering can drive them on. It is very important that the final mixture should be in proper proportions. This is secured, first of all, by regulating the admission of the gases. The diameter of each of the four radial orifices which constitute the nozzles for the introduction of the acetylene into the tip, the diameter of longitudinal contraction which serves the same purpose for the oxygen and the volumetric capacity of the mixing chamber C, all must enter into the problem of securing the proper mixture of acetylene and oxygen in the ratio of 1: 1.28. It is desirable, in view of the many different kinds of work to which the torch is applicable, to provide a variety of diameters for the exit channel, in order to produce welding flames of different sizes, (see Fig. 2).

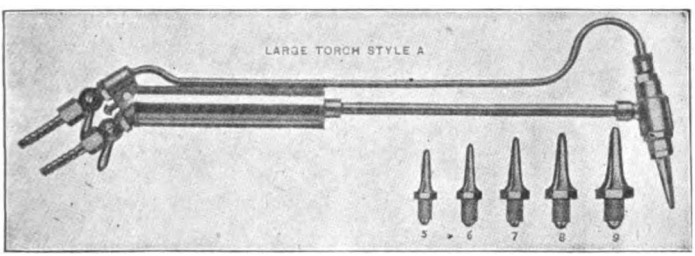


Fig. 2
Welding Torch and Tips.

The dimensioning of the tip corresponds to certain standard pressures of the oxygen and acetylene. These are liable to slight variations which are compensated for by means of adjustment of the supply cocks.

But the form of the central flame is the final test. Instead of making adjustment by means of the cocks on the torch itself, the reducing valves at the sources of supply may be adjusted and leave the cocks on the torch wide open. However, the flame should be inspected now and then to ascertain whether conditions are being preserved.

The oxygen in its tank may be kept at a very considerable pressure, but as it flows out, the pressure falls. In order both to avoid the excessive pressure of the reservoir and the fluctuations attendant upon driving the torch supply directly from it, a reducing valve, Fig. 3, is used. The larger indicator, Fig. 3, shows

the pressure in the reservoir, the smaller marks the pressure after reduction. The reducing valve automatically brings the varying

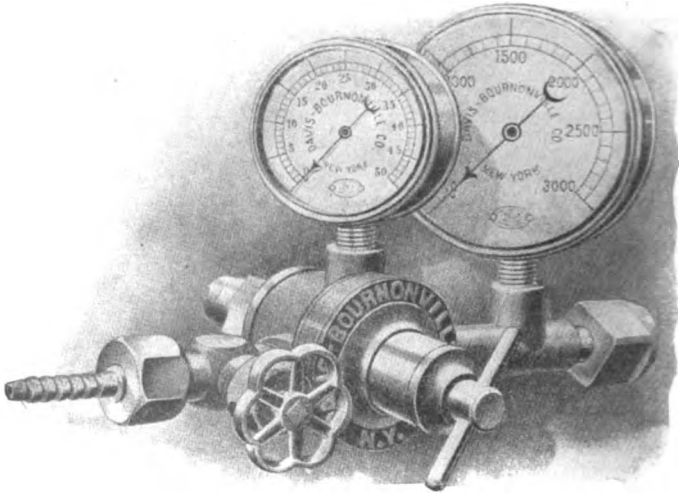


Fig. 3
Oxygen Regulators.

pressure of the supply to the fixed point desired for the torch. The acetylene regulator which accomplishes the same results for acetylene that the reducing valve does for the oxygen is shown in Fig. 4.

Acetylene is an endothermic substance. That is, it absorbs heat upon its formation from hydrogen and carbon, and liberates heat upon dissociation into its elements.

Acetylene is commercially prepared by bringing calcium carbide into the presence of water. If water is present in excess of the weight required, then a further reaction takes place—the resulting lime becoming slaked lime.

In the generation of acetylene by this method, a very considerable amount of heat is liberated in spite of the individual endothermic character of the gas itself. To meet the difficulty that might thus arise in the process of generation a large excess of water is employed. The water then furnishes, not only the hydrogen for the acetylene, but acts as an absorber of the heat liberated. Acetylene can also be prepared by dropping water upon calcium carbide, but there is then no provision for the absorption of the heat of chemical action.

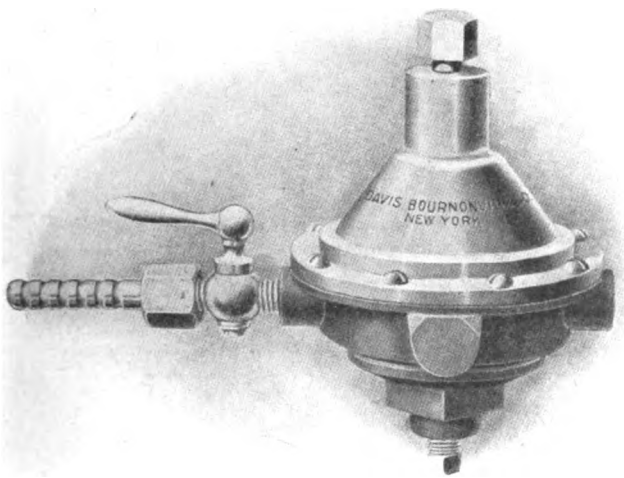


Fig. 4
Acetylene Pressure Regulator.

Fig. 5 is a sectional view of a pressure generator, which produces acetylene under pressure. At the top of the tank, the carbide hopper is represented by dotted lines. The chemical is introduced into this receptacle by removing the plug kk. The tank is about two-thirds full of water. Into this the carbide, of nut size (1inch x ⅜ inch), is dropped. An agitator is located at the bottom, as shown by dotted lines. This is rotatable from the outside by means of the crank shown on the left. The slaked lime residium may be drawn off at the extreme bottom. The gas, upon being generated, rises to the space above the water-level and passes out of the tank at the upper right side. It then passes into the tube OQ, at whose top is a controlling diaphragm connected with a lever and weight. These control the pressure at which the acetylene is produced in the following manner: There is a clockwork motor on top of the tank. This is run by means of the weights at the left. When the extreme left end of the lever is at a certain point of depression or slightly below it, it acts through the agency of a fan governor to permit the operation of the clock-work. When it is raised above this position, the clock-work and the consequent feeding of carbide increases the pressure of the acetylene being generated, the raw-hide diaphragm X is expanded upward, and so lifts the lever. If this continues, the left hand end of the lever will rise sufficiently to stop the clock-work. Generation of

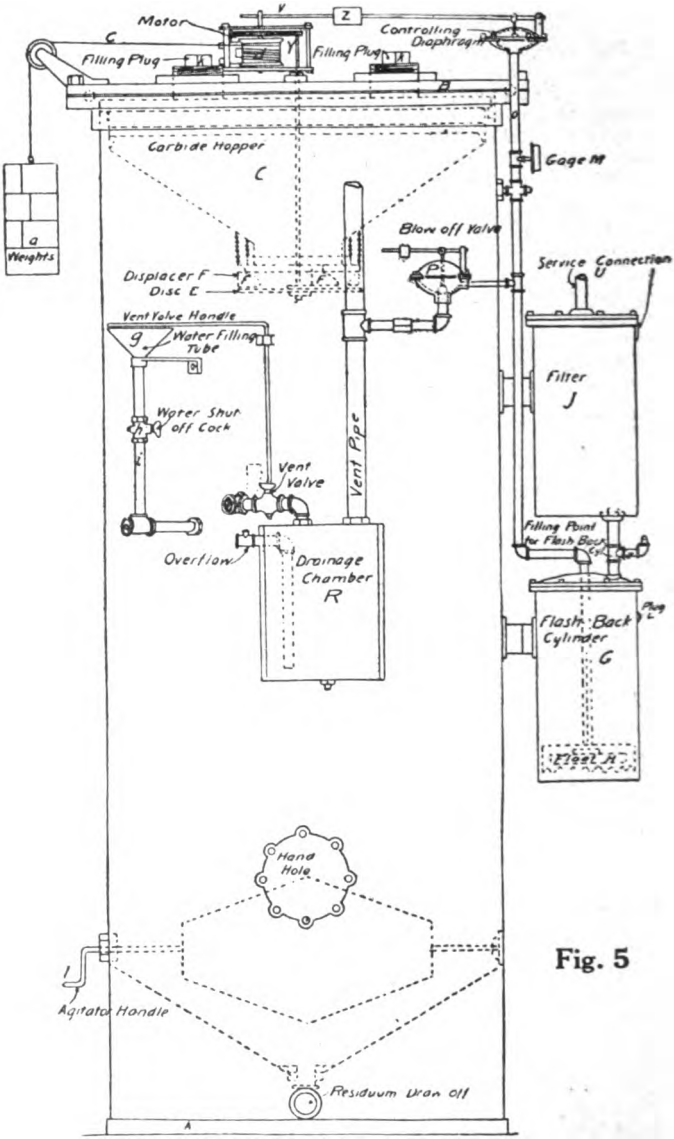

Motor
Controlling Diaphragm
Filling Plug
Filling Plug
Carbide Hopper
C
Gage M
a
Weights
Blow off Valve
Service Connection
Displacer F
Disc E
Vent Valve Handle
g
Water Filling Tube
Filter
J
Water Shut off Cock
Vent Valve
Vent Pipe
Filling Point for Flash Back
Overflow
Drainage Chamber
R
Flash Back Cylinder
G
Plug L
Hand Hole
Agitator Handle
Residuum Drain Off
A

Fig. 5

acetylene immediately ceases. The pressure at which the acetylene will be generated depends upon the amount of resistance of the lever to the diaphragm X. By attending to it, and the gauge at M adjusting the weight Z on the lever, this pressure may be set at any point desired. The maximum pressure recommended is 10 pounds per square inch. At P is a safety valve which may be set, say, at 15 pounds.

The clock-work operates a horizontal circular disk E, which is rotatable on a vertical axis. This disc really forms the bottom of the carbide hopper, although it is some little distance below the actual discharge opening. A series of semi-stationary guides FF, hung by chains and occupying in part the space between the disc and hopper, direct the pieces of carbide on the disc to its edge during operation. The chemical is fed by being dropped off the edge of the disc into the water below. The current of gas as it is generated, passes down the vertical tube OQ and into the flash-back cylinder G. This is kept nearly full of water. The gas is conducted to the bottom, when it is permitted to rise to the surface and pass off into the chamber J, which is filled with suitable filtration material. Thence is passed upwards into the service pipe U.

The oxygen necessary may be generated or it may be purchased in tanks from companies who manufacture it.

Since acetylene is an explosive gas, a flash-back from the tip is a thing to be taken into serious account. However, in this generator, the maximum pressure is limited to 15 pounds per square inch. At this low pressure, the acetylene will not explode unless mixed with air or oxygen, provided the temperature is not permitted to reach the ignition point, 896 degrees Fahr. However, this is provided against in several different ways. The exit of the tip is much larger than the oxygen inlet. This, taken in connection with the fact that the final exit is in a direct line with the incoming strong current of oxygen, would seem to provide fairly well for the evacuation of the oxygen from the tip, even though the acetylene pressure should momentarily cease. However, if the mouth of the tip should become stopped up, it is conceivable that serious results might follow. But the construction of the torch is such that the acetylene passes through an enlarged chamber before reaching the tip. This is, in fact, the handle of the torch and is filled with asbestos and mineral wool. Before a flame could reach the tank, it would have to pass through the filter J, where porous material again obstructs its passage. However, if the flame should succeed in getting through both the handle and this filter, it would next encounter the water in tank G. Here nearly the entire depth would have to be passed through, in order that the flame might pass into the tube I and on into the tank. Therefore, with the flash-back tank properly filled, there is little danger of the flame retreating from the tip to the tank.

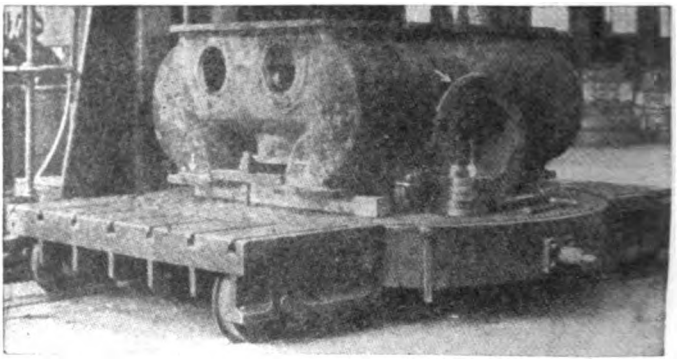


Fig. 6

Repair of Heavy Craked Casting.

With such intense and manageable heat as that afforded by the inner flame of oxy-acetylene torch it is possible to unite cast-iron to cast-iron, steel to iron, steel to brass, etc. The union is effected by fusion. Two pieces of cast-iron may be joined by melting a film of the surfaces which it is desired to involve in the joint, and also melting a quantity of new cast-iron in between and then effecting a unification of the whole. Or, by joining two surfaces by the intervention of an independent piece of metal soldering is accomplished. But the fusion process differs from welding in that no pressure is exerted and actual fusion takes place. It differs from soldering in that actual fusion of the surfaces occurs.

To effect a weld of cast-iron to cast-iron the edges which it is desired to unite are chamfered off to form a V-shaped groove having a right angle at the bottom. Beginning at the point of the V, the metal is fused and puddled, and the weld started with material supplied from its sides. When this beginning has gotten fairly under way, additional metal may be supplied. Using the torch, this is puddled together with metal from the sides of the V.

It will be seen that, since it is necessary to fuse the metal of the work, a high temperature must be maintained at the sides of the V. If these are thin, but little trouble will be experienced. But as the metal involved becomes more massive, difficulty arises. To meet this difficulty, the edges must be pre-heated. Indeed, it would seem that success in dealing with pretty much any size of parts is dependent merely upon the ability to secure a sufficient and properly distributed pre-heating.

Many times, when castings are examined for defects, blow holes are found. Projecting parts may have been broken off, all of which may be economically repaired and recovered by this process.

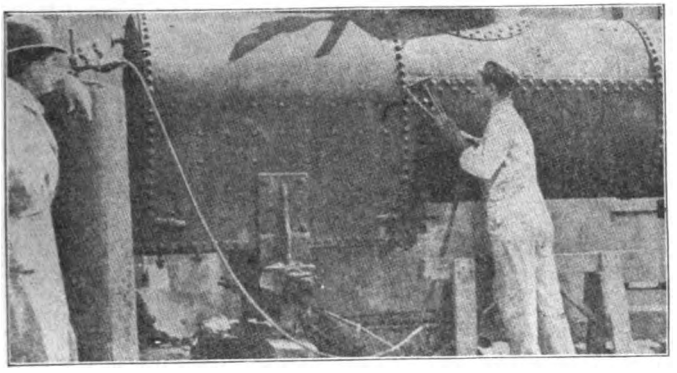


Fig. 7

Welding Rupture in Firebox Sheet.

The cutting of steel by actual burning is made commercially practicable by means of the oxy-acetylene blow-pipe on account of the high temperature which it is capable of developing. Steel to be cut is first heated by the torch flame to the melting point and then a special supply of oxygen under higher pressure than that used for the torch flame is delivered through a separate tube directly at the cutting point (see Fig. 8) which is arranged close to the flame jet to take advantage of the high temperature created by the latter.

Each torch is fitted to receive the attachment for cutting steel and iron (other than cast iron) and can be attached or detached easily

By moving the double nozzle along at proper speed a smooth cut is obtained by burning that can be made practically as deep and narrow as one made by a tool, due to the localization of heat possible with the very high temperature. The metal disappearing from the cut is in great measure combined with the oxygen to form oxide of iron, passing off in the form of fine particles. The oxide is the reason for the considerable supply of oxygen necessary.

To make a cut ¼-inch wide, 1 foot long, in 1-inch of steel would remove 3 cu. inches of metal weighing about 13½ oz. The amount of carbon contained is small, and, assuming the iron to be burned entirely to oxide, the cutting will take 5 1-7 oz. of oxygen, or 3.55 cu. ft. at atmospheric pressure. This amount of oxygen must be supplied in the time of making the 1-ft. length of cut. Temperature will not take the place of oxygen, nor will oxygen take the place of temperature.

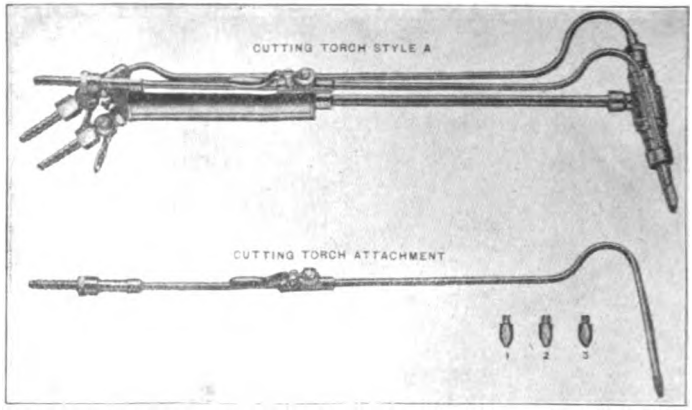
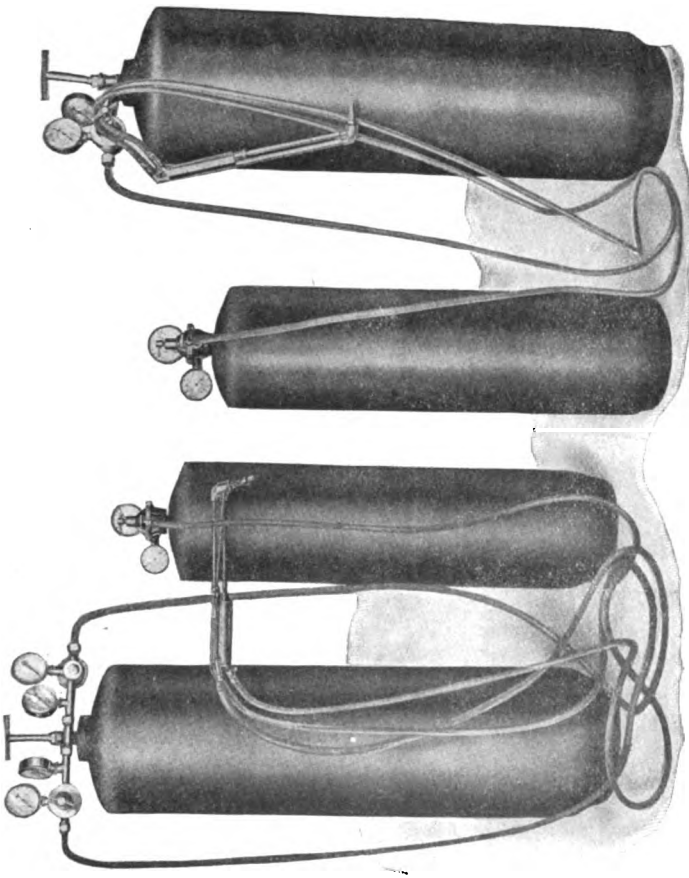


Fig. 8

Cutting Torch and Tips.

Steel can be readily cut by the oxy-acetylene process, but not cast iron. The difference between steel and gray cast iron lies in the carbon and its condition. In steel all the carbon present is chemically combined with the iron and cannot exceed about 2 per cent. Gray cast iron contains more than this and much of its carbon exists uncombined. The trouble may not be so much because of the total amount of carbon present as the manner in which it exists, partly uncombined. Cast iron can be fused and welded readily by the oxy-acetylene process, but not cut. The materials to which the cutting process is applicable are commercial wrought iron and steel. Steel can be cut in any form, whether rolled, forged or cast, and very thick sections as well as thin ones. The metal loss is but little, as the activity is purely local. A bar of steel 6 inches square can be cut in two with a cut about ⅛-inch wide. A little more metal is involved because of slight irregularities, but this is a small matter. Steel 6 inches thick can be cut at the rate of about 1 foot in 3 minutes. The oxygen requisite for such a cut is about 20 cu. ft., plus the oxygen for the heating tip, which costs about 2½ cents a cubic foot

Fig. 9 shows the portable units for welding and cutting. The portable welding unit may be converted into a cutting unit by placing a tee connection on the oxygen cylinder and adding an oxygen indicator and regulator with a hose connection for furnishing a supply of pure oxygen gas.



Portable Cutting Unit. Portable Welding Unit.

Fig. 9

In the compression of acetylene for portable use the acetylene is dissolved in acetone, which is capable of absorbing twenty-five times its own volume with each atmosphere of pressure. The process consists of filling high pressure steel tanks with porous material and acetone and compressing the acetylene into the same, from which it can be used as required.

It is important that the nozzle be the right size. The waste of steel involved in making too wide a cut may be disregarded, but not the waste of gas and labor. A cut 3/16 inch wide when ⅛-inch is practicable, means the disintegration of 50 per cent. more metal and employment of 50 per cent. more gas and labor. The smallest nozzles practicable should be used to save, not merely steel, but the expense required to consume it. Very deep cuts can be made with very thin jets.

An acetylene welding and cutting machine for use where straight-line welding and cutting operations have to be carried out, especially in connection with repetition work is shown in Fig. 10. This machine consists of a cylindrical upright 6 or 7 feet in height, which carries a long hollow arm projecting for 6 or 7 feet on one side. By means of a rack and pinion this arm, which carries a long screw, may be adjusted to any height desired. At the base of the upright, pulleys mounted on a short horizontal shaft are driven from a countershaft above. At one end of the short shaft a friction pinion is arranged which contacts with a suitable disc mounted on a vertical shaft. This latter shaft and a rotatable rod arranged in the hollow arm are connected by bevel gears. At the outer end of the arm an arrangement of gears enables the inclosed rod to drive the screw. The turning of this screw operates a carriage back and forth horizontally along the arm. Upon the carriage are mounted the torch and its controlling fixtures. The work is placed or secured on a suitable fixed table, and flexible tubes bring the oxygen and acetylene to the torch. The tip is practically the ordinary form, and it is arranged at an angle of 40 or 45 degrees to the horizontal, this angle being to the rear of the welding movement.

If the weld is to be a flat one and of inconsiderable length, the two pieces are clamped in the exact relative positions they are to occupy finally. The carriage with the torch moves evenly along at the proper rate of speed.

To weld two strips edge to edge at an angle of 90 degrees the strips are placed on the sides of an angle bar and clamped securely in position with clamping strips inserted between the outer faces of the work and the jaws of the clamps.

Where the form and character of the work do not prohibit, pre-heating by cheap methods can be employed, thus effecting a saving both in the consumption of the gases and time. Where pre-heating is used before passing under the torch it is claimed that the work can be welded at a speed of about 26 inches to 28 inches per minute.

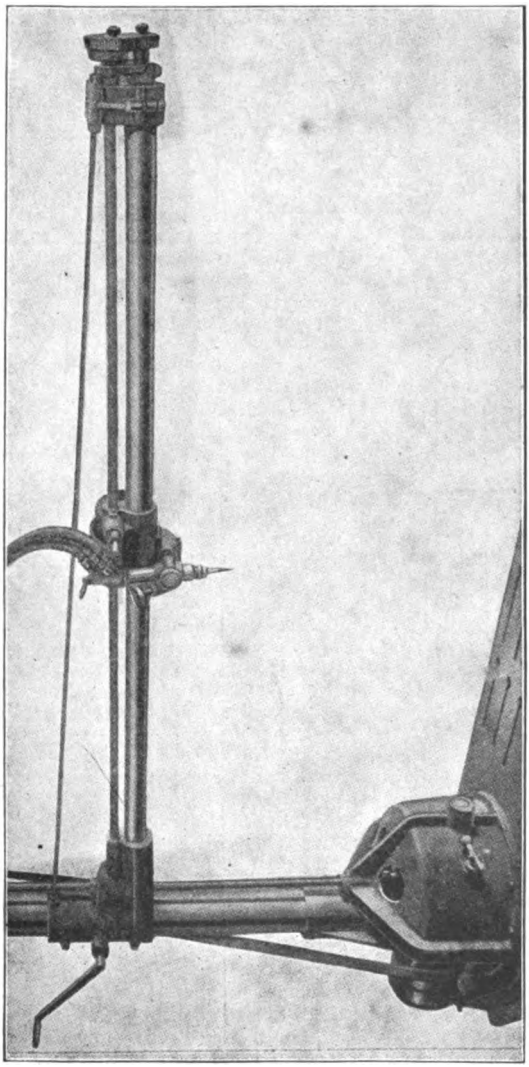


Fig. 10
Oxy-Acetylene Welding and Cutting Machine.

Thermit Welding.—Another form of welding metal is by the use of thermit. This form of welding is especially successful for welding large and thick pieces of metal as it produces an exceedingly strong joint.

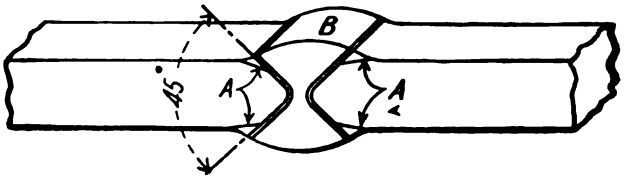


Fig. 11

Thermit Weld made on Frame Under Engine.

It is not used to such an extent in welding smaller pieces as the oxy-acetylene process, because in making the weld a small bulging is produced, see Fig. 11, which, since the joint is so

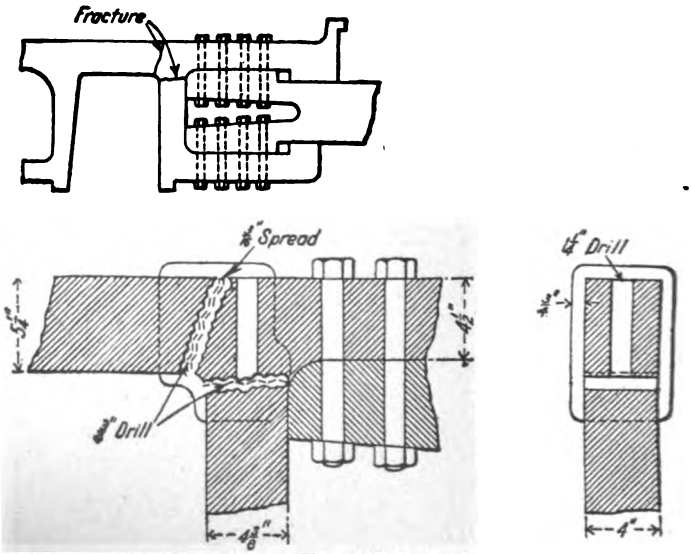


Fig. 12

Thermit Weld. Locomotive Frame.

hard, is exceedingly difficult to plane or grind down to the original surface, thereby not allowing as neat a job to be made.

Fig. 12 shows a compound weld made by thermit. The 1¼-inch hole is drilled through the top rail to give the thermit a better opportunity to circulate and the frame will also preheat more uniformly. The pedestal jaw was spread apart 3/16-inch.

To prevent the frame from upsetting while preheating and welding, the opposite frame was expanded with a slow charcoal fire. When a frame is broken in two or more places in the front pedestal and the engine requires general repairs the broken pedestal is replaced by a steel one, which is already machined. Some of these require three welds, as this type of pedestal is welded to the front end of the frame forward of the guide-yoke, thus cutting out the splice and making a continuous frame.

APPENDIX.

NATURAL SINES AND COSINES.

′	0°		1°		2°		3°		4°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.00000	1	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	60
1	.00029	1	.01774	.99984	.03519	.99938	.05263	.99861	.07005	.99754	59
2	.00058	1	.01803	.99984	.03548	.99937	.05292	.99860	.07034	.99752	58
3	.00087	1	.01832	.99983	.03577	.99936	.05321	.99858	.07063	.99750	57
4	.00116	1	.01862	.99983	.03606	.99935	.05350	.99857	.07092	.99748	56
5	.00145	1	.01891	.99982	.03635	.99934	.05379	.99855	.07121	.99746	55
6	.00175	1	.01920	.99982	.03664	.99933	.05408	.99854	.07150	.99744	54
7	.00204	1	.01949	.99981	.03693	.99932	.05437	.99852	.07179	.99742	53
8	.00233	1	.01978	.99980	.03723	.99931	.05466	.99851	.07208	.99740	52
9	.00262	1	.02007	.99980	.03752	.99930	.05495	.99849	.07237	.99738	51
10	.00291	1	.02036	.99979	.03781	.99929	.05524	.99847	.07266	.99736	50
11	.00320	.99999	.02065	.99979	.03810	.99927	.05553	.99846	.07295	.99734	49
12	.00349	.99999	.02094	.99978	.03839	.99926	.05582	.99844	.07324	.99731	48
13	.00378	.99999	.02123	.99977	.03868	.99925	.05611	.99842	.07353	.99729	47
14	.00407	.99999	.02152	.99977	.03897	.99924	.05640	.99841	.07382	.99727	46
15	.00436	.99999	.02181	.99976	.03926	.99923	.05669	.99839	.07411	.99725	45
16	.00465	.99999	.02211	.99976	.03955	.99922	.05698	.99838	.07440	.99723	44
17	.00495	.99999	.02240	.99975	.03984	.99921	.05727	.99836	.07469	.99721	43
18	.00524	.99999	.02269	.99974	.04013	.99919	.05756	.99834	.07498	.99719	42
19	.00553	.99998	.02298	.99974	.04042	.99918	.05785	.99833	.07527	.99716	41
20	.00582	.99998	.02327	.99973	.04071	.99917	.05814	.99831	.07556	.99714	40
21	.00611	.99998	.02356	.99972	.04100	.99916	.05844	.99829	.07585	.99712	39
22	.00640	.99998	.02385	.99972	.04129	.99915	.05873	.99827	.07614	.99710	38
23	.00669	.99998	.02414	.99971	.04159	.99913	.05902	.99826	.07643	.99708	37
24	.00698	.99998	.02443	.99970	.04188	.99912	.05931	.99824	.07672	.99705	36
25	.00727	.99997	.02472	.99969	.04217	.99911	.05960	.99822	.07701	.99703	35
26	.00756	.99997	.02501	.99969	.04246	.99910	.05989	.99821	.07730	.99701	34
27	.00785	.99997	.02530	.99968	.04275	.99909	.06018	.99819	.07759	.99699	33
28	.00814	.99997	.02560	.99967	.04304	.99907	.06047	.99817	.07788	.99696	32
29	.00844	.99996	.02589	.99966	.04333	.99906	.06076	.99815	.07817	.99694	31
30	.00873	.99996	.02618	.99966	.04362	.99905	.06105	.99813	.07846	.99692	30
31	.00902	.99996	.02647	.99965	.04391	.99904	.06134	.99812	.07875	.99689	29
32	.00931	.99996	.02676	.99964	.04420	.99902	.06163	.99810	.07904	.99687	28
33	.00960	.99995	.02705	.99963	.04449	.99901	.06192	.99808	.07933	.99685	27
34	.00989	.99995	.02734	.99963	.04478	.99900	.06221	.99806	.07962	.99683	26
35	.01018	.99995	.02763	.99962	.04507	.99898	.06250	.99804	.07991	.99680	25
36	.01047	.99995	.02792	.99961	.04536	.99897	.06279	.99803	.08020	.99678	24
37	.01076	.99994	.02821	.99960	.04565	.99896	.06308	.99801	.08049	.99676	23
38	.01105	.99994	.02850	.99959	.04594	.99894	.06337	.99799	.08078	.99673	22
39	.01134	.99994	.02879	.99959	.04623	.99893	.06366	.99797	.08107	.99671	21
40	.01164	.99993	.02908	.99958	.04653	.99892	.06395	.99795	.08136	.99668	20
41	.01193	.99993	.02938	.99957	.04682	.99890	.06424	.99793	.08165	.99666	19
42	.01222	.99993	.02967	.99956	.04711	.99889	.06453	.99792	.08194	.99664	18
43	.01251	.99992	.02996	.99955	.04740	.99888	.06482	.99790	.08223	.99661	17
44	.01280	.99992	.03025	.99954	.04769	.99886	.06511	.99788	.08252	.99659	16
45	.01309	.99991	.03054	.99953	.04798	.99885	.06540	.99786	.08281	.99657	15
46	.01338	.99991	.03083	.99952	.04827	.99883	.06569	.99784	.08310	.99654	14
47	.01367	.99991	.03112	.99952	.04856	.99882	.06598	.99782	.08339	.99652	13
48	.01396	.99990	.03141	.99951	.04885	.99881	.06627	.99780	.08368	.99649	12
49	.01425	.99990	.03170	.99950	.04914	.99879	.06656	.99778	.08397	.99647	11
50	.01454	.99989	.03199	.99949	.04943	.99878	.06685	.99776	.08426	.99644	10
51	.01483	.99989	.03228	.99948	.04972	.99876	.06714	.99774	.08455	.99642	9
52	.01513	.99989	.03257	.99947	.05001	.99875	.06743	.99772	.08484	.99639	8
53	.01542	.99988	.03286	.99946	.05030	.99873	.06773	.99770	.08513	.99637	7
54	.01571	.99988	.03316	.99945	.05059	.99872	.06802	.99768	.08542	.99635	6
55	.01600	.99987	.03345	.99944	.05088	.99870	.06831	.99766	.08571	.99632	5
56	.01629	.99987	.03374	.99943	.05117	.99869	.06860	.99764	.08600	.99630	4
57	.01658	.99986	.03403	.99942	.05146	.99867	.06889	.99762	.08629	.99627	3
58	.01687	.99986	.03432	.99941	.05175	.99866	.06918	.99760	.08658	.99625	2
59	.01716	.99985	.03461	.99940	.05205	.99864	.06947	.99758	.08687	.99622	1
60	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	.08716	.99619	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	89°		88°		87°		86°		85°		

NATURAL SINES AND COSINES.

′	5°		6°		7°		8°		9°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.08716	.99619	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769	60
1	.08745	.99617	.10482	.99449	.12216	.99251	.13946	.99023	.15672	.98764	59
2	.08774	.99614	.10511	.99446	.12245	.99248	.13975	.99019	.15701	.98760	58
3	.08803	.99612	.10540	.99443	.12274	.99244	.14004	.99015	.15730	.98755	57
4	.08831	.99609	.10569	.99440	.12302	.99240	.14033	.99011	.15758	.98751	56
5	.08860	.99607	.10597	.99437	.12331	.99237	.14061	.99006	.15787	.98746	55
6	.08889	.99604	.10626	.99434	.12360	.99233	.14090	.99002	.15816	.98741	54
7	.08918	.99602	.10655	.99431	.12389	.99230	.14119	.98998	.15845	.98737	53
8	.08947	.99599	.10684	.99428	.12418	.99226	.14148	.98994	.15873	.98732	52
9	.08976	.99596	.10713	.99424	.12447	.99222	.14177	.98990	.15902	.98728	51
10	.09005	.99594	.10742	.99421	.12476	.99219	.14205	.98986	.15931	.98723	50
11	.09034	.99591	.10771	.99418	.12504	.99215	.14234	.98982	.15959	.98718	49
12	.09063	.99588	.10800	.99415	.12533	.99211	.14263	.98978	.15988	.98714	48
13	.09092	.99586	.10829	.99412	.12562	.99208	.14292	.98973	.16017	.98709	47
14	.09121	.99583	.10858	.99409	.12591	.99204	.14320	.98969	.16046	.98704	46
15	.09150	.99580	.10887	.99406	.12620	.99200	.14349	.98965	.16074	.98700	45
16	.09179	.99578	.10916	.99402	.12649	.99197	.14378	.98961	.16103	.98695	44
17	.09208	.99575	.10945	.99399	.12678	.99193	.14407	.98957	.16132	.98690	43
18	.09237	.99572	.10973	.99396	.12706	.99189	.14436	.98953	.16160	.98686	42
19	.09266	.99570	.11002	.99393	.12735	.99186	.14464	.98948	.16189	.98681	41
20	.09295	.99567	.11031	.99390	.12764	.99182	.14493	.98944	.16218	.98676	40
21	.09324	.99564	.11060	.99386	.12793	.99178	.14522	.98940	.16246	.98671	39
22	.09353	.99562	.11089	.99383	.12822	.99175	.14551	.98936	.16275	.98667	38
23	.09382	.99559	.11118	.99380	.12851	.99171	.14580	.98931	.16304	.98662	37
24	.09411	.99556	.11147	.99377	.12880	.99167	.14608	.98927	.16333	.98657	36
25	.09440	.99553	.11176	.99374	.12908	.99163	.14637	.98923	.16361	.98652	35
26	.09469	.99551	.11205	.99370	.12937	.99160	.14666	.98919	.16390	.98648	34
27	.09498	.99548	.11234	.99367	.12966	.99156	.14695	.98914	.16419	.98643	33
28	.09527	.99545	.11263	.99364	.12995	.99152	.14723	.98910	.16447	.98638	32
29	.09556	.99542	.11291	.99360	.13024	.99148	.14752	.98906	.16476	.98633	31
30	.09585	.99540	.11320	.99357	.13053	.99144	.14781	.98902	.16505	.98629	30
31	.09614	.99537	.11349	.99354	.13081	.99141	.14810	.98897	.16533	.98624	29
32	.09642	.99534	.11378	.99351	.13110	.99137	.14838	.98893	.16562	.98619	28
33	.09671	.99531	.11407	.99347	.13139	.99133	.14867	.98889	.16591	.98614	27
34	.09700	.99528	.11436	.99344	.13168	.99129	.14896	.98884	.16620	.98609	26
35	.09729	.99526	.11465	.99341	.13197	.99125	.14925	.98880	.16648	.98604	25
36	.09758	.99523	.11494	.99337	.13226	.99122	.14954	.98876	.16677	.98600	24
37	.09787	.99520	.11523	.99334	.13254	.99118	.14982	.98871	.16706	.98595	23
38	.09816	.99517	.11552	.99331	.13283	.99114	.15011	.98867	.16734	.98590	22
39	.09845	.99514	.11580	.99327	.13312	.99110	.15040	.98863	.16763	.98585	21
40	.09874	.99511	.11609	.99324	.13341	.99106	.15069	.98858	.16792	.98580	20
41	.09903	.99508	.11638	.99320	.13370	.99102	.15097	.98854	.16820	.98575	19
42	.09932	.99506	.11667	.99317	.13399	.99098	.15126	.98849	.16849	.98570	18
43	.09961	.99503	.11696	.99314	.13427	.99094	.15155	.98845	.16878	.98565	17
44	.09990	.99500	.11725	.99310	.13456	.99091	.15184	.98841	.16906	.98561	16
45	.10019	.99497	.11754	.99307	.13485	.99087	.15212	.98836	.16935	.98556	15
46	.10048	.99494	.11783	.99303	.13514	.99083	.15241	.98832	.16964	.98551	14
47	.10077	.99491	.11812	.99300	.13543	.99079	.15270	.98827	.16992	.98546	13
48	.10106	.99488	.11840	.99297	.13572	.99075	.15299	.98823	.17021	.98541	12
49	.10135	.99485	.11869	.99293	.13600	.99071	.15327	.98818	.17050	.98536	11
50	.10164	.99482	.11898	.99290	.13629	.99067	.15356	.98814	.17078	.98531	10
51	.10192	.99479	.11927	.99286	.13658	.99063	.15385	.98809	.17107	.98526	9
52	.10221	.99476	.11956	.99283	.13687	.99059	.15414	.98805	.17136	.98521	8
53	.10250	.99473	.11985	.99279	.13716	.99055	.15442	.98800	.17164	.98516	7
54	.10279	.99470	.12014	.99276	.13744	.99051	.15471	.98796	.17193	.98511	6
55	.10308	.99467	.12043	.99272	.13773	.99047	.15500	.98791	.17222	.98506	5
56	.10337	.99464	.12071	.99269	.13802	.99043	.15529	.98787	.17250	.98501	4
57	.10366	.99461	.12100	.99265	.13831	.99039	.15557	.98782	.17279	.98496	3
58	.10395	.99458	.12129	.99262	.13860	.99035	.15586	.98778	.17308	.98491	2
59	.10424	.99455	.12158	.99258	.13889	.99031	.15615	.98773	.17336	.98486	1
60	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769	.17365	.98481	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	84°		83°		82°		81°		80°		

Natural Sines and Cosines.

′	10°		11°		12°		13°		14°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.17365	.98481	.19081	.98163	.20791	.97815	.22495	.97437	.24192	.97030	60
1	.17393	.98476	.19109	.98157	.20820	.97809	.22523	.97430	.24220	.97023	59
2	.17422	.98471	.19138	.98152	.20848	.97803	.22552	.97424	.24249	.97015	58
3	.17451	.98466	.19167	.98146	.20877	.97797	.22580	.97417	.24277	.97008	57
4	.17479	.98461	.19195	.98140	.20905	.97791	.22608	.97411	.24305	.97001	56
5	.17508	.98455	.19224	.98135	.20933	.97784	.22637	.97404	.24333	.96994	55
6	.17537	.98450	.19252	.98129	.20962	.97778	.22665	.97398	.24362	.96987	54
7	.17565	.98445	.19281	.98124	.20990	.97772	.22693	.97391	.24390	.96980	53
8	.17594	.98440	.19309	.98118	.21019	.97766	.22722	.97384	.24418	.96973	52
9	.17623	.98435	.19338	.98112	.21047	.97760	.22750	.97378	.24446	.96966	51
10	.17651	.98430	.19366	.98107	.21076	.97754	.22778	.97371	.24474	.96959	50
11	.17680	.98425	.19395	.98101	.21104	.97748	.22807	.97365	.24503	.96952	49
12	.17708	.98420	.19423	.98096	.21132	.97742	.22835	.97358	.24531	.96945	48
13	.17737	.98414	.19452	.98090	.21161	.97735	.22863	.97351	.24559	.96937	47
14	.17766	.98409	.19481	.98084	.21189	.97729	.22892	.97345	.24587	.96930	46
15	.17794	.98404	.19509	.98079	.21218	.97723	.22920	.97338	.24615	.96923	45
16	.17823	.98399	.19538	.98073	.21246	.97717	.22948	.97331	.24644	.96916	44
17	.17852	.98394	.19566	.98067	.21275	.97711	.22977	.97325	.24672	.96909	43
18	.17880	.98389	.19595	.98061	.21303	.97705	.23005	.97318	.24700	.96902	42
19	.17909	.98383	.19623	.98056	.21331	.97698	.23033	.97311	.24728	.96894	41
20	.17937	.98378	.19652	.98050	.21360	.97692	.23062	.97304	.24756	.96887	40
21	.17966	.98373	.19680	.98044	.21388	.97686	.23090	.97298	.24784	.96880	39
22	.17995	.98368	.19709	.98039	.21417	.97680	.23118	.97291	.24813	.96873	38
23	.18023	.98362	.19737	.98033	.21445	.97673	.23146	.97284	.24841	.96866	37
24	.18052	.98357	.19766	.98027	.21474	.97667	.23175	.97278	.24869	.96858	36
25	.18081	.98352	.19794	.98021	.21502	.97661	.23203	.97271	.24897	.96851	35
26	.18109	.98347	.19823	.98016	.21530	.97655	.23231	.97264	.24925	.96844	34
27	.18138	.98341	.19851	.98010	.21559	.97648	.23260	.97257	.24954	.96837	33
28	.18166	.98336	.19880	.98004	.21587	.97642	.23288	.97251	.24982	.96829	32
29	.18195	.98331	.19908	.97998	.21616	.97636	.23316	.97244	.25010	.96822	31
30	.18224	.98325	.19937	.97992	.21644	.97630	.23345	.97237	.25038	.96815	30
31	.18252	.98320	.19965	.97987	.21672	.97623	.23373	.97230	.25066	.96807	29
32	.18281	.98315	.19994	.97981	.21701	.97617	.23401	.97223	.25094	.96800	28
33	.18309	.98310	.20022	.97975	.21729	.97611	.23429	.97217	.25122	.96793	27
34	.18338	.98304	.20051	.97969	.21758	.97604	.23458	.97210	.25151	.96786	26
35	.18367	.98299	.20079	.97963	.21786	.97598	.23486	.97203	.25179	.96778	25
36	.18395	.98294	.20108	.97958	.21814	.97592	.23514	.97196	.25207	.96771	24
37	.18424	.98288	.20136	.97952	.21843	.97585	.23542	.97189	.25235	.96764	23
38	.18452	.98283	.20165	.97946	.21871	.97579	.23571	.97182	.25263	.96756	22
39	.18481	.98277	.20193	.97940	.21899	.97573	.23599	.97176	.25291	.96749	21
40	.18509	.98272	.20222	.97934	.21928	.97566	.23627	.97169	.25320	.96742	20
41	.18538	.98267	.20250	.97928	.21956	.97560	.23656	.97162	.25348	.96734	19
42	.18567	.98261	.20279	.97922	.21985	.97553	.23684	.97155	.25376	.96727	18
43	.18595	.98256	.20307	.97916	.22013	.97547	.23712	.97148	.25404	.96719	17
44	.18624	.98250	.20336	.97910	.22041	.97541	.23740	.97141	.25432	.96712	16
45	.18652	.98245	.20364	.97905	.22070	.97534	.23769	.97134	.25460	.96705	15
46	.18681	.98240	.20393	.97899	.22098	.97528	.23797	.97127	.25488	.96697	14
47	.18710	.98234	.20421	.97893	.22126	.97521	.23825	.97120	.25516	.96690	13
48	.18738	.98229	.20450	.97887	.22155	.97515	.23853	.97113	.25545	.96682	12
49	.18767	.98223	.20478	.97881	.22183	.97508	.23882	.97106	.25573	.96675	11
50	.18795	.98218	.20507	.97875	.22212	.97502	.23910	.97100	.25601	.96667	10
51	.18824	.98212	.20535	.97869	.22240	.97496	.23938	.97093	.25629	.96660	9
52	.18852	.98207	.20563	.97863	.22268	.97489	.23966	.97086	.25657	.96653	8
53	.18881	.98201	.20592	.97857	.22297	.97483	.23995	.97079	.25685	.96645	7
54	.18910	.98196	.20620	.97851	.22325	.97476	.24023	.97072	.25713	.96638	6
55	.18938	.98190	.20649	.97845	.22353	.97470	.24051	.97065	.25741	.96630	5
56	.18967	.98185	.20677	.97839	.22382	.97463	.24079	.97058	.25769	.96623	4
57	.18995	.98179	.20706	.97833	.22410	.97457	.24108	.97051	.25798	.96615	3
58	.19024	.98174	.20734	.97827	.22438	.97450	.24136	.97044	.25826	.96608	2
59	.19052	.98168	.20763	.97821	.22467	.97444	.24164	.97037	.25854	.96600	1
60	.19081	.98163	.20791	.97815	.22495	.97437	.24192	.97030	.25882	.96593	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	79°		78°		77°		76°		75°		

Natural Sines and Cosines.

′	15°		16°		17°		18°		19°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.25882	.96593	.27564	.96126	.29237	.95630	.30902	.95106	.32557	.94552	60
1	.25910	.96585	.27592	.96118	.29265	.95622	.30929	.95097	.32584	.94542	59
2	.25938	.96578	.27620	.96110	.29293	.95613	.30957	.95088	.32612	.94533	58
3	.25966	.96570	.27648	.96102	.29321	.95605	.30985	.95079	.32639	.94523	57
4	.25994	.96562	.27676	.96094	.29348	.95596	.31012	.95070	.32667	.94514	56
5	.26022	.96555	.27704	.96086	.29376	.95588	.31040	.95061	.32694	.94504	55
6	.26050	.96547	.27731	.96078	.29404	.95579	.31068	.95052	.32722	.94495	54
7	.26079	.96540	.27759	.96070	.29432	.95571	.31095	.95043	.32749	.94485	53
8	.26107	.96532	.27787	.96062	.29460	.95562	.31123	.95033	.32777	.94476	52
9	.26135	.96524	.27815	.96054	.29487	.95554	.31151	.95024	.32804	.94466	51
10	.26163	.96517	.27843	.96046	.29515	.95545	.31178	.95015	.32832	.94457	50
11	.26191	.96509	.27871	.96037	.29543	.95536	.31206	.95006	.32859	.94447	49
12	.26219	.96502	.27899	.96029	.29571	.95528	.31233	.94997	.32887	.94438	48
13	.26247	.96494	.27927	.96021	.29599	.95519	.31261	.94988	.32914	.94428	47
14	.26275	.96486	.27955	.96013	.29626	.95511	.31289	.94979	.32942	.94418	46
15	.26303	.96479	.27983	.96005	.29654	.95502	.31316	.94970	.32969	.94409	45
16	.26331	.96471	.28011	.95997	.29682	.95493	.31344	.94961	.32997	.94399	44
17	.26359	.96463	.28039	.95989	.29710	.95485	.31372	.94952	.33024	.94390	43
18	.26387	.96456	.28067	.95981	.29737	.95476	.31399	.94943	.33051	.94380	42
19	.26415	.96448	.28095	.95972	.29765	.95467	.31427	.94933	.33079	.94370	41
20	.26443	.96440	.28123	.95964	.29793	.95459	.31454	.94924	.33106	.94361	40
21	.26471	.96433	.28150	.95956	.29821	.95450	.31482	.94915	.33134	.94351	39
22	.26500	.96425	.28178	.95948	.29849	.95441	.31510	.94906	.33161	.94342	38
23	.26528	.96417	.28206	.95940	.29876	.95433	.31537	.94897	.33189	.94332	37
24	.26556	.96410	.28234	.95931	.29904	.95424	.31565	.94888	.33216	.94322	36
25	.26584	.96402	.28262	.95923	.29932	.95415	.31593	.94878	.33244	.94313	35
26	.26612	.96394	.28290	.95915	.29960	.95407	.31620	.94869	.33271	.94303	34
27	.26640	.96386	.28318	.95907	.29987	.95398	.31648	.94860	.33298	.94293	33
28	.26668	.96379	.28346	.95898	.30015	.95389	.31675	.94851	.33326	.94284	32
29	.26696	.96371	.28374	.95890	.30043	.95380	.31703	.94842	.33353	.94274	31
30	.26724	.96363	.28402	.95882	.30071	.95372	.31730	.94832	.33381	.94264	30
31	.26752	.96355	.28429	.95874	.30098	.95363	.31758	.94823	.33408	.94254	29
32	.26780	.96347	.28457	.95865	.30126	.95354	.31786	.94814	.33436	.94245	28
33	.26808	.96340	.28485	.95857	.30154	.95345	.31813	.94805	.33463	.94235	27
34	.26836	.96332	.28513	.95849	.30182	.95337	.31841	.94795	.33490	.94225	26
35	.26864	.96324	.28541	.95841	.30209	.95328	.31868	.94786	.33518	.94215	25
36	.26892	.96316	.28569	.95832	.30237	.95319	.31896	.94777	.33545	.94206	24
37	.26920	.96308	.28597	.95824	.30265	.95310	.31923	.94768	.33573	.94196	23
38	.26948	.96301	.28625	.95816	.30292	.95301	.31951	.94758	.33600	.94186	22
39	.26976	.96293	.28652	.95807	.30320	.95293	.31979	.94749	.33627	.94176	21
40	.27004	.96285	.28680	.95799	.30348	.95284	.32006	.94740	.33655	.94167	20
41	.27032	.96277	.28708	.95791	.30376	.95275	.32034	.94730	.33682	.94157	19
42	.27060	.96269	.28736	.95782	.30403	.95266	.32061	.94721	.33710	.94147	18
43	.27088	.96261	.28764	.95774	.30431	.95257	.32089	.94712	.33737	.94137	17
44	.27116	.96253	.28792	.95766	.30459	.95248	.32116	.94702	.33764	.94127	16
45	.27144	.96246	.28820	.95757	.30486	.95240	.32144	.94693	.33792	.94118	15
46	.27172	.96238	.28847	.95749	.30514	.95231	.32171	.94684	.33819	.94108	14
47	.27200	.96230	.28875	.95740	.30542	.95222	.32199	.94674	.33846	.94098	13
48	.27228	.96222	.28903	.95732	.30570	.95213	.32227	.94665	.33874	.94088	12
49	.27256	.96214	.28931	.95724	.30597	.95204	.32254	.94656	.33901	.94078	11
50	.27284	.96206	.28959	.95715	.30625	.95195	.32282	.94646	.33929	.94068	10
51	.27312	.96198	.28987	.95707	.30653	.95186	.32309	.94637	.33956	.94058	9
52	.27340	.96190	.29015	.95698	.30680	.95177	.32337	.94627	.33983	.94049	8
53	.27368	.96182	.29042	.95690	.30708	.95168	.32364	.94618	.34011	.94039	7
54	.27396	.96174	.29070	.95681	.30736	.95159	.32392	.94609	.34038	.94029	6
55	.27424	.96166	.29098	.95673	.30763	.95150	.32419	.94599	.34065	.94019	5
56	.27452	.96158	.29126	.95664	.30791	.95142	.32447	.94590	.34093	.94009	4
57	.27480	.96150	.29154	.95656	.30819	.95133	.32474	.94580	.34120	.93999	3
58	.27508	.96142	.29182	.95647	.30846	.95124	.32502	.94571	.34147	.93989	2
59	.27536	.96134	.29209	.95639	.30874	.95115	.32529	.94561	.34175	.93979	1
60	.27564	.96126	.29237	.95630	.30902	.95106	.32557	.94552	.34202	.93969	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	74°		73°		72°		71°		70°		

Natural Sines and Cosines.

′	20°		21°		22°		23°		24°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.34202	.93969	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	60
1	.34229	.93959	.35864	.93348	.37488	.92707	.39100	.92039	.40700	.91343	59
2	.34257	.93949	.35891	.93337	.37515	.92697	.39127	.92028	.40727	.91331	58
3	.34284	.93939	.35918	.93327	.37542	.92686	.39153	.92016	.40753	.91319	57
4	.34311	.93929	.35945	.93316	.37569	.92675	.39180	.92005	.40780	.91307	56
5	.34339	.93919	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295	55
6	.34366	.93909	.36000	.93295	.37622	.92653	.39234	.91982	.40833	.91283	54
7	.34393	.93899	.36027	.93285	.37649	.92642	.39260	.91971	.40860	.91272	53
8	.34421	.93889	.36054	.93274	.37676	.92631	.39287	.91959	.40886	.91260	52
9	.34448	.93879	.36081	.93264	.37703	.92620	.39314	.91948	.40913	.91248	51
10	.34475	.93869	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236	50
11	.34503	.93859	.36135	.93243	.37757	.92598	.39367	.91925	.40966	.91224	49
12	.34530	.93849	.36162	.93232	.37784	.92587	.39394	.91914	.40992	.91212	48
13	.34557	.93839	.36190	.93222	.37811	.92576	.39421	.91902	.41019	.91200	47
14	.34584	.93829	.36217	.93211	.37838	.92565	.39448	.91891	.41045	.91188	46
15	.34612	.93819	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176	45
16	.34639	.93809	.36271	.93190	.37892	.92543	.39501	.91868	.41098	.91164	44
17	.34666	.93799	.36298	.93180	.37919	.92532	.39528	.91856	.41125	.91152	43
18	.34694	.93789	.36325	.93169	.37946	.92521	.39555	.91845	.41151	.91140	42
19	.34721	.93779	.36352	.93159	.37973	.92510	.39581	.91833	.41178	.91128	41
20	.34748	.93769	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116	40
21	.34775	.93759	.36406	.93137	.38026	.92488	.39635	.91810	.41231	.91104	39
22	.34803	.93748	.36434	.93127	.38053	.92477	.39661	.91799	.41257	.91092	38
23	.34830	.93738	.36461	.93116	.38080	.92466	.39688	.91787	.41284	.91080	37
24	.34857	.93728	.36488	.93106	.38107	.92455	.39715	.91775	.41310	.91068	36
25	.34884	.93718	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056	35
26	.34912	.93708	.36542	.93084	.38161	.92432	.39768	.91752	.41363	.91044	34
27	.34939	.93698	.36569	.93074	.38188	.92421	.39795	.91741	.41390	.91032	33
28	.34966	.93688	.36596	.93063	.38215	.92410	.39822	.91729	.41416	.91020	32
29	.34993	.93677	.36623	.93052	.38241	.92399	.39848	.91718	.41443	.91008	31
30	.35021	.93667	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996	30
31	.35048	.93657	.36677	.93031	.38295	.92377	.39902	.91694	.41496	.90984	29
32	.35075	.93647	.36704	.93020	.38322	.92366	.39928	.91683	.41522	.90972	28
33	.35102	.93637	.36731	.93010	.38349	.92355	.39955	.91671	.41549	.90960	27
34	.35130	.93626	.36758	.92999	.38376	.92343	.39982	.91660	.41575	.90948	26
35	.35157	.93616	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936	25
36	.35184	.93606	.36812	.92978	.38430	.92321	.40035	.91636	.41628	.90924	24
37	.35211	.93596	.36839	.92967	.38456	.92310	.40062	.91625	.41655	.90911	23
38	.35239	.93585	.36867	.92956	.38483	.92299	.40088	.91613	.41681	.90899	22
39	.35266	.93575	.36894	.92945	.38510	.92287	.40115	.91601	.41707	.90887	21
40	.35293	.93565	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875	20
41	.35320	.93555	.36948	.92924	.38564	.92265	.40168	.91578	.41760	.90863	19
42	.35347	.93544	.36975	.92913	.38591	.92254	.40195	.91566	.41787	.90851	18
43	.35375	.93534	.37002	.92902	.38617	.92243	.40221	.91555	.41813	.90839	17
44	.35402	.93524	.37029	.92892	.38644	.92231	.40248	.91543	.41840	.90826	16
45	.35429	.93514	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814	15
46	.35456	.93503	.37083	.92870	.38698	.92209	.40301	.91519	.41892	.90802	14
47	.35484	.93493	.37110	.92859	.38725	.92198	.40328	.91508	.41919	.90790	13
48	.35511	.93483	.37137	.92849	.38752	.92186	.40355	.91496	.41945	.90778	12
49	.35538	.93472	.37164	.92838	.38778	.92175	.40381	.91484	.41972	.90766	11
50	.35565	.93462	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753	10
51	.35592	.93452	.37218	.92816	.38832	.92152	.40434	.91461	.42024	.90741	9
52	.35619	.93441	.37245	.92805	.38859	.92141	.40461	.91449	.42051	.90729	8
53	.35647	.93431	.37272	.92794	.38886	.92130	.40488	.91437	.42077	.90717	7
54	.35674	.93420	.37299	.92784	.38912	.92119	.40514	.91425	.42104	.90704	6
55	.35701	.93410	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692	5
56	.35728	.93400	.37353	.92762	.38966	.92096	.40567	.91402	.42156	.90680	4
57	.35755	.93389	.37380	.92751	.38993	.92085	.40594	.91390	.42183	.90668	3
58	.35782	.93379	.37407	.92740	.39020	.92073	.40621	.91378	.42209	.90655	2
59	.35810	.93368	.37434	.92729	.39046	.92062	.40647	.91366	.42235	.90643	1
60	.35837	.93358	.37461	.92718	.39073	.92051	.40674	.91355	.42262	.90631	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	69°		68°		67°		66°		65°		

Natural Sines and Cosines.

′	25°		26°		27°		28°		29°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.42262	.90631	.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	60
1	.42288	.90618	.43863	.89867	.45425	.89087	.46973	.88281	.48506	.87448	59
2	.42315	.90606	.43889	.89854	.45451	.89074	.46999	.88267	.48532	.87434	58
3	.42341	.90594	.43916	.89841	.45477	.89061	.47024	.88254	.48557	.87420	57
4	.42367	.90582	.43942	.89828	.45503	.89048	.47050	.88240	.48583	.87406	56
5	.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	.48608	.87391	55
6	.42420	.90557	.43994	.89803	.45554	.89021	.47101	.88213	.48634	.87377	54
7	.42446	.90545	.44020	.89790	.45580	.89008	.47127	.88199	.48659	.87363	53
8	.42473	.90532	.44046	.89777	.45606	.88995	.47153	.88185	.48684	.87349	52
9	.42499	.90520	.44072	.89764	.45632	.88981	.47178	.88172	.48710	.87335	51
10	.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	.48735	.87321	50′
11	.42552	.90495	.44124	.89739	.45684	.88955	.47229	.88144	.48761	.87306	49
12	.42578	.90483	.44151	.89726	.45710	.88942	.47255	.88130	.48786	.87292	48
13	.42604	.90470	.44177	.89713	.45736	.88928	.47281	.88117	.48811	.87278	47
14	.42631	.90458	.44203	.89700	.45762	.88915	.47306	.88103	.48837	.87264	46
15	.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	.48862	.87250	45
16	.42683	.90433	.44255	.89674	.45813	.88888	.47358	.88075	.48888	.87235	44
17	.42709	.90421	.44281	.89662	.45839	.88875	.47383	.88062	.48913	.87221	43
18	.42736	.90408	.44307	.89649	.45865	.88862	.47409	.88048	.48938	.87207	42
19	.42762	.90396	.44333	.89636	.45891	.88848	.47434	.88034	.48964	.87193	41
20	.42788	.90383	.44359	.89623	.45917	.88835	.47460	.88020	.48989	.87178	40
21	.42815	.90371	.44385	.89610	.45942	.88822	.47486	.88006	.49014	.87164	39
22	.42841	.90358	.44411	.89597	.45968	.88808	.47511	.87993	.49040	.87150	38
23	.42867	.90346	.44437	.89584	.45994	.88795	.47537	.87979	.49065	.87136	37
24	.42894	.90334	.44464	.89571	.46020	.88782	.47562	.87965	.49090	.87121	36
25	.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	.49116	.87107	35
26	.42946	.90309	.44516	.89545	.46072	.88755	.47614	.87937	.49141	.87093	34
27	.42972	.90296	.44542	.89532	.46097	.88741	.47639	.87923	.49166	.87079	33
28	.42999	.90284	.44568	.89519	.46123	.88728	.47665	.87909	.49192	.87064	32
29	.43025	.90271	.44594	.89506	.46149	.88715	.47690	.87896	.49217	.87050	31
30	.43051	.90259	.44620	.89493	.46175	.88701	.47716	.87882	.49242	.87036	30
31	.43077	.90246	.44646	.89480	.46201	.88688	.47741	.87868	.49268	.87021	29
32	.43104	.90233	.44672	.89467	.46226	.88674	.47767	.87854	.49293	.87007	28
33	.43130	.90221	.44698	.89454	.46252	.88661	.47793	.87840	.49318	.86993	27
34	.43156	.90208	.44724	.89441	.46278	.88647	.47818	.87826	.49344	.86978	26
35	.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	.49369	.86964	25
36	.43209	.90183	.44776	.89415	.46330	.88620	.47869	.87798	.49394	.86949	24
37	.43235	.90171	.44802	.89402	.46355	.88607	.47895	.87784	.49419	.86935	23
38	.43261	.90158	.44828	.89389	.46381	.88593	.47920	.87770	.49445	.86921	22
39	.43287	.90146	.44854	.89376	.46407	.88580	.47946	.87756	.49470	.86906	21
40	.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87743	.49495	.86892	20
41	.43340	.90120	.44906	.89350	.46458	.88553	.47997	.87729	.49521	.86878	19
42	.43366	.90108	.44932	.89337	.46484	.88539	.48022	.87715	.49546	.86863	18
43	.43392	.90095	.44958	.89324	.46510	.88526	.48048	.87701	.49571	.86849	17
44	.43418	.90082	.44984	.89311	.46536	.88512	.48073	.87687	.49596	.86834	16
45	.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	.49622	.86820	15
46	.43471	.90057	.45036	.89285	.46587	.88485	.48124	.87659	.49647	.86805	14
47	.43497	.90045	.45062	.89272	.46613	.88472	.48150	.87645	.49672	.86791	13
48	.43523	.90032	.45088	.89259	.46639	.88458	.48175	.87631	.49697	.86777	12
49	.43549	.90019	.45114	.89245	.46664	.88445	.48201	.87617	.49723	.86762	11
50	.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	.49748	.86748	10
51	.43602	.89994	.45166	.89219	.46716	.88417	.48252	.87589	.49773	.86733	9
52	.43628	.89981	.45192	.89206	.46742	.88404	.48277	.87575	.49798	.86719	8
53	.43654	.89968	.45218	.89193	.46767	.88390	.48303	.87561	.49824	.86704	7
54	.43680	.89956	.45243	.89180	.46793	.88377	.48328	.87546	.49849	.86690	6
55	.43706	.89943	.45269	.89167	.46819	.88363	.48354	.87532	.49874	.86675	5
56	.43733	.89930	.45295	.89153	.46844	.88349	.48379	.87518	.49899	.86661	4
57	.43759	.89918	.45321	.89140	.46870	.88336	.48405	.87504	.49924	.86646	3
58	.43785	.89905	.45347	.89127	.46896	.88322	.48430	.87490	.49950	.86632	2
59	.43811	.89892	.45373	.89114	.46921	.88308	.48456	.87476	.49975	.86617	1
60	.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	.50000	.86603	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	64°		63°		62°		61°		60°		

Natural Sines and Cosines.

′	30°		31°		32°		33°		34°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.50000	.86603	.51504	.85717	.52992	.84805	.54464	.83867	.55919	.82904	60
1	.50025	.86588	.51529	.85702	.53017	.84789	.54488	.83851	.55943	.82887	59
2	.50050	.86573	.51554	.85687	.53041	.84774	.54513	.83835	.55968	.82871	58
3	.50076	.86559	.51579	.85672	.53066	.84759	.54537	.83819	.55992	.82855	57
4	.50101	.86544	.51604	.85657	.53091	.84743	.54561	.83804	.56016	.82839	56
5	.50126	.86530	.51628	.85642	.53115	.84728	.54586	.83788	.56040	.82822	55
6	.50151	.86515	.51653	.85627	.53140	.84712	.54610	.83772	.56064	.82806	54
7	.50176	.86501	.51678	.85612	.53164	.84697	.54635	.83756	.56088	.82790	53
8	.50201	.86486	.51703	.85597	.53189	.84681	.54659	.83740	.56112	.82773	52
9	.50227	.86471	.51728	.85582	.53214	.84666	.54683	.83724	.56136	.82757	51
10	.50252	.86457	.51753	.85567	.53238	.84650	.54708	.83708	.56160	.82741	50
11	.50277	.86442	.51778	.85551	.53263	.84635	.54732	.83692	.56184	.82724	49
12	.50302	.86427	.51803	.85536	.53288	.84619	.54756	.83676	.56208	.82708	48
13	.50327	.86413	.51828	.85521	.53312	.84604	.54781	.83660	.56232	.82692	47
14	.50352	.86398	.51852	.85506	.53337	.84588	.54805	.83645	.56256	.82675	46
15	.50377	.86384	.51877	.85491	.53361	.84573	.54829	.83629	.56280	.82659	45
16	.50403	.86369	.51902	.85476	.53386	.84557	.54854	.83613	.56305	.82643	44
17	.50428	.86354	.51927	.85461	.53411	.84542	.54878	.83597	.56329	.82626	43
18	.50453	.86340	.51952	.85446	.53435	.84526	.54902	.83581	.56353	.82610	42
19	.50478	.86325	.51977	.85431	.53460	.84511	.54927	.83565	.56377	.82593	41
20	.50503	.86310	.52002	.85416	.53484	.84495	.54951	.83549	.56401	.82577	40
21	.50528	.86295	.52026	.85401	.53509	.84480	.54975	.83533	.56425	.82561	39
22	.50553	.86281	.52051	.85385	.53534	.84464	.54999	.83517	.56449	.82544	38
23	.50578	.86266	.52076	.85370	.53558	.84448	.55024	.83501	.56473	.82528	37
24	.50603	.86251	.52101	.85355	.53583	.84433	.55048	.83485	.56497	.82511	36
25	.50628	.86237	.52126	.85340	.53607	.84417	.55072	.83469	.56521	.82495	35
26	.50654	.86222	.52151	.85325	.53632	.84402	.55097	.83453	.56545	.82478	34
27	.50679	.86207	.52175	.85310	.53656	.84386	.55121	.83437	.56569	.82462	33
28	.50704	.86192	.52200	.85294	.53681	.84370	.55145	.83421	.56593	.82446	32
29	.50729	.86178	.52225	.85279	.53705	.84355	.55169	.83405	.56617	.82429	31
30	.50754	.86163	.52250	.85264	.53730	.84339	.55194	.83389	.56641	.82413	30
31	.50779	.86148	.52275	.85249	.53754	.84324	.55218	.83373	.56665	.82396	29
32	.50804	.86133	.52299	.85234	.53779	.84308	.55242	.83356	.56689	.82380	28
33	.50829	.86119	.52324	.85218	.53804	.84292	.55266	.83340	.56713	.82363	27
34	.50854	.86104	.52349	.85203	.53828	.84277	.55291	.83324	.56736	.82347	26
35	.50879	.86089	.52374	.85188	.53853	.84261	.55315	.83308	.56760	.82330	25
36	.50904	.86074	.52399	.85173	.53877	.84245	.55339	.83292	.56784	.82314	24
37	.50929	.86059	.52423	.85157	.53902	.84230	.55363	.83276	.56808	.82297	23
38	.50954	.86045	.52448	.85142	.53926	.84214	.55388	.83260	.56832	.82281	22
39	.50979	.86030	.52473	.85127	.53951	.84198	.55412	.83244	.56856	.82264	21
40	.51004	.86015	.52498	.85112	.53975	.84182	.55436	.83228	.56880	.82248	20
41	.51029	.86000	.52522	.85096	.54000	.84167	.55460	.83212	.56904	.82231	19
42	.51054	.85985	.52547	.85081	.54024	.84151	.55484	.83195	.56928	.82214	18
43	.51079	.85970	.52572	.85066	.54049	.84135	.55509	.83179	.56952	.82198	17
44	.51104	.85956	.52597	.85051	.54073	.84120	.55533	.83163	.56976	.82181	16
45	.51129	.85941	.52621	.85035	.54097	.84104	.55557	.83147	.57000	.82165	15
46	.51154	.85926	.52646	.85020	.54122	.84088	.55581	.83131	.57024	.82148	14
47	.51179	.85911	.52671	.85005	.54146	.84072	.55605	.83115	.57047	.82132	13
48	.51204	.85896	.52696	.84989	.54171	.84057	.55630	.83098	.57071	.82115	12
49	.51229	.85881	.52720	.84974	.54195	.84041	.55654	.83082	.57095	.82098	11
50	.51254	.85866	.52745	.84959	.54220	.84025	.55678	.83066	.57119	.82082	10
51	.51279	.85851	.52770	.84943	.54244	.84009	.55702	.83050	.57143	.82065	9
52	.51304	.85836	.52794	.84928	.54269	.83994	.55726	.83034	.57167	.82048	8
53	.51329	.85821	.52819	.84913	.54293	.83978	.55750	.83017	.57191	.82032	7
54	.51354	.85806	.52844	.84897	.54317	.83962	.55775	.83001	.57215	.82015	6
55	.51379	.85792	.52869	.84882	.54342	.83946	.55799	.82985	.57238	.81999	5
56	.51404	.85777	.52893	.84866	.54366	.83930	.55823	.82969	.57262	.81982	4
57	.51429	.85762	.52918	.84851	.54391	.83915	.55847	.82953	.57286	.81965	3
58	.51454	.85747	.52943	.84836	.54415	.83899	.55871	.82936	.57310	.81949	2
59	.51479	.85732	.52967	.84820	.54440	.83883	.55895	.82920	.57334	.81932	1
60	.51504	.85717	.52992	.84805	.54464	.83867	.55919	.82904	.57358	.81915	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	59°		58°		57°		56°		55°		

Natural Sines and Cosines.

′	35°		36°		37°		38°		39°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.57338	.81915	.58779	.80902	.60182	.79864	.61566	.78801	.62932	.77715	60
1	.57381	.81899	.58802	.80885	.60205	.79846	.61589	.78783	.62955	.77696	59
2	.57405	.81882	.58826	.80867	.60228	.79829	.61612	.78765	.62977	.77678	58
3	.57429	.81865	.58849	.80850	.60251	.79811	.61635	.78747	.63000	.77660	57
4	.57453	.81848	.58873	.80833	.60274	.79793	.61658	.78729	.63022	.77641	56
5	.57477	.81832	.58896	.80816	.60298	.79776	.61681	.78711	.63045	.77623	55
6	.57501	.81815	.58920	.80799	.60321	.79758	.61704	.78694	.63068	.77605	54
7	.57524	.81798	.58943	.80782	.60344	.79741	.61726	.78676	.63090	.77586	53
8	.57548	.81782	.58967	.80765	.60367	.79723	.61749	.78658	.63113	.77568	52
9	.57572	.81765	.58990	.80748	.60390	.79706	.61772	.78640	.63135	.77550	51
10	.57596	.81748	.59014	.80730	.60414	.79688	.61795	.78622	.63158	.77531	50
11	.57619	.81731	.59037	.80713	.60437	.79671	.61818	.78604	.63180	.77513	49
12	.57643	.81714	.59061	.80696	.60460	.79653	.61841	.78586	.63203	.77494	48
13	.57667	.81698	.59084	.80679	.60483	.79635	.61864	.78568	.63225	.77476	47
14	.57691	.81681	.59108	.80662	.60506	.79618	.61887	.78550	.63248	.77458	46
15	.57715	.81664	.59131	.80644	.60529	.79600	.61909	.78532	.63271	.77439	45
16	.57738	.81647	.59154	.80627	.60553	.79583	.61932	.78514	.63293	.77421	44
17	.57762	.81631	.59178	.80610	.60576	.79565	.61955	.78496	.63316	.77402	43
18	.57786	.81614	.59201	.80593	.60599	.79547	.61978	.78478	.63338	.77384	42
19	.57810	.81597	.59225	.80576	.60622	.79530	.62001	.78460	.63361	.77366	41
20	.57833	.81580	.59248	.80558	.60645	.79512	.62024	.78442	.63383	.77347	40
21	.57857	.81563	.59272	.80541	.60668	.79494	.62046	.78424	.63406	.77329	39
22	.57881	.81546	.59295	.80524	.60691	.79477	.62069	.78405	.63428	.77310	38
23	.57904	.81530	.59318	.80507	.60714	.79459	.62092	.78387	.63451	.77292	37
24	.57928	.81513	.59342	.80489	.60738	.79441	.62115	.78369	.63473	.77273	36
25	.57952	.81496	.59365	.80472	.60761	.79424	.62138	.78351	.63496	.77255	35
26	.57976	.81479	.59389	.80455	.60784	.79406	.62160	.78333	.63518	.77236	34
27	.57999	.81462	.59412	.80438	.60807	.79388	.62183	.78315	.63540	.77218	33
28	.58023	.81445	.59436	.80420	.60830	.79371	.62206	.78297	.63563	.77199	32
29	.58047	.81428	.59459	.80403	.60853	.79353	.62229	.78279	.63585	.77181	31
30	.58070	.81412	.59482	.80386	.60876	.79335	.62251	.78261	.63608	.77162	30
31	.58094	.81395	.59506	.80368	.60899	.79318	.62274	.78243	.63630	.77144	29
32	.58118	.81378	.59529	.80351	.60922	.79300	.62297	.78225	.63653	.77125	28
33	.58141	.81361	.59552	.80334	.60945	.79282	.62320	.78206	.63675	.77107	27
34	.58165	.81344	.59576	.80316	.60968	.79264	.62342	.78188	.63698	.77088	26
35	.58189	.81327	.59599	.80299	.60991	.79247	.62365	.78170	.63720	.77070	25
36	.58212	.81310	.59622	.80282	.61015	.79229	.62388	.78152	.63742	.77051	24
37	.58236	.81293	.59646	.80264	.61038	.79211	.62411	.78134	.63765	.77033	23
38	.58260	.81276	.59669	.80247	.61061	.79193	.62433	.78116	.63787	.77014	22
39	.58283	.81259	.59693	.80230	.61084	.79176	.62456	.78098	.63810	.76996	21
40	.58307	.81242	.59716	.80212	.61107	.79158	.62479	.78079	.63832	.76977	20
41	.58330	.81225	.59739	.80195	.61130	.79140	.62502	.78061	.63854	.76959	19
42	.58354	.81208	.59763	.80178	.61153	.79122	.62524	.78043	.63877	.76940	18
43	.58378	.81191	.59786	.80160	.61176	.79105	.62547	.78025	.63899	.76921	17
44	.58401	.81174	.59809	.80143	.61199	.79087	.62570	.78007	.63922	.76903	16
45	.58425	.81157	.59832	.80125	.61222	.79069	.62592	.77988	.63944	.76884	15
46	.58449	.81140	.59856	.80108	.61245	.79051	.62615	.77970	.63966	.76866	14
47	.58472	.81123	.59879	.80091	.61268	.79033	.62638	.77952	.63989	.76847	13
48	.58496	.81106	.59902	.80073	.61291	.79016	.62660	.77934	.64011	.76828	12
49	.58519	.81089	.59926	.80056	.61314	.78998	.62683	.77916	.64033	.76810	11
50	.58543	.81072	.59949	.80038	.61337	.78980	.62706	.77897	.64056	.76791	10
51	.58567	.81055	.59972	.80021	.61360	.78962	.62728	.77879	.64078	.76772	9
52	.58590	.81038	.59995	.80003	.61383	.78944	.62751	.77861	.64100	.76754	8
53	.58614	.81021	.60019	.79986	.61406	.78926	.62774	.77843	.64123	.76735	7
54	.58637	.81004	.60042	.79968	.61429	.78908	.62796	.77824	.64145	.76717	6
55	.58661	.80987	.60065	.79951	.61451	.78891	.62819	.77806	.64167	.76698	5
56	.58684	.80970	.60089	.79934	.61474	.78873	.62842	.77788	.64190	.76679	4
57	.58708	.80953	.60112	.79916	.61497	.78855	.62864	.77769	.64212	.76661	3
58	.58731	.80936	.60135	.79899	.61520	.78837	.62887	.77751	.64234	.76642	2
59	.58755	.80919	.60158	.79881	.61543	.78819	.62909	.77733	.64256	.76623	1
60	.58779	.80902	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	54°		53°		52°		51°		50°		

Natural Sines and Cosines.

′	40°		41°		42°		43°		44°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.64279	.76604	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	60
1	.64301	.76586	.65628	.75452	.66935	.74295	.68221	.73116	.69487	.71914	59
2	.64323	.76567	.65650	.75433	.66956	.74276	.68242	.73096	.69508	.71894	58
3	.64346	.76548	.65672	.75414	.66978	.74256	.68264	.73076	.69529	.71873	57
4	.64368	.76530	.65694	.75395	.66999	.74237	.68285	.73056	.69549	.71853	56
5	.64390	.76511	.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
6	.64412	.76492	.65738	.75356	.67043	.74198	.68327	.73016	.69591	.71813	54
7	.64435	.76473	.65759	.75337	.67064	.74178	.68349	.72996	.69612	.71792	53
8	.64457	.76454	.65781	.75318	.67086	.74159	.68370	.72976	.69633	.71772	52
9	.64479	.76436	.65803	.75299	.67107	.74139	.68391	.72957	.69654	.71752	51
10	.64501	.76417	.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
11	.64524	.76398	.65847	.75261	.67151	.74100	.68434	.72917	.69696	.71711	49
12	.64546	.76380	.65869	.75241	.67172	.74080	.68455	.72897	.69717	.71691	48
13	.64568	.76361	.65891	.75222	.67194	.74061	.68476	.72877	.69737	.71671	47
14	.64590	.76342	.65913	.75203	.67215	.74041	.68497	.72857	.69758	.71650	46
15	.64612	.76323	.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
16	.64635	.76304	.65956	.75165	.67258	.74002	.68539	.72817	.69800	.71610	44
17	.64657	.76286	.65978	.75146	.67280	.73983	.68561	.72797	.69821	.71590	43
18	.64679	.76267	.66000	.75126	.67301	.73963	.68582	.72777	.69842	.71569	42
19	.64701	.76248	.66022	.75107	.67323	.73944	.68603	.72757	.69862	.71549	41
20	.64723	.76229	.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
21	.64746	.76210	.66066	.75069	.67366	.73904	.68645	.72717	.69904	.71508	39
22	.64768	.76192	.66088	.75050	.67387	.73885	.68666	.72697	.69925	.71488	38
23	.64790	.76173	.66109	.75030	.67409	.73865	.68688	.72677	.69946	.71468	37
24	.64812	.76154	.66131	.75011	.67430	.73846	.68709	.72657	.69966	.71447	36
25	.64834	.76135	.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
26	.64856	.76116	.66175	.74973	.67473	.73806	.68751	.72617	.70008	.71407	34
27	.64878	.76097	.66197	.74953	.67495	.73787	.68772	.72597	.70029	.71386	33
28	.64901	.76078	.66218	.74934	.67516	.73767	.68793	.72577	.70049	.71366	32
29	.64923	.76059	.66240	.74915	.67538	.73747	.68814	.72557	.70070	.71345	31
30	.64945	.76041	.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
31	.64967	.76022	.66284	.74876	.67580	.73708	.68857	.72517	.70112	.71305	29
32	.64989	.76003	.66306	.74857	.67602	.73688	.68878	.72497	.70132	.71284	28
33	.65011	.75984	.66327	.74838	.67623	.73669	.68899	.72477	.70153	.71264	27
34	.65033	.75965	.66349	.74818	.67645	.73649	.68920	.72457	.70174	.71243	26
35	.65055	.75946	.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
36	.65077	.75927	.66393	.74780	.67688	.73610	.68962	.72417	.70215	.71203	24
37	.65100	.75908	.66414	.74760	.67709	.73590	.68983	.72397	.70236	.71182	23
38	.65122	.75889	.66436	.74741	.67730	.73570	.69004	.72377	.70257	.71162	22
39	.65144	.75870	.66458	.74722	.67752	.73551	.69025	.72357	.70277	.71141	21
40	.65166	.75851	.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
41	.65188	.75832	.66501	.74683	.67795	.73511	.69067	.72317	.70319	.71100	19
42	.65210	.75813	.66523	.74664	.67816	.73491	.69088	.72297	.70339	.71080	18
43	.65232	.75794	.66545	.74644	.67837	.73472	.69109	.72277	.70360	.71059	17
44	.65254	.75775	.66566	.74625	.67859	.73452	.69130	.72257	.70381	.71039	16
45	.65276	.75756	.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
46	.65298	.75738	.66610	.74586	.67901	.73413	.69172	.72216	.70422	.70998	14
47	.65320	.75719	.66632	.74567	.67923	.73393	.69193	.72196	.70443	.70978	13
48	.65342	.75700	.66653	.74548	.67944	.73373	.69214	.72176	.70463	.70957	12
49	.65364	.75680	.66675	.74528	.67965	.73353	.69235	.72156	.70484	.70937	11
50	.65386	.75661	.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
51	.65408	.75642	.66718	.74489	.68008	.73314	.69277	.72116	.70525	.70896	9
52	.65430	.75623	.66740	.74470	.68029	.73294	.69298	.72095	.70546	.70875	8
53	.65452	.75604	.66762	.74451	.68051	.73274	.69319	.72075	.70567	.70855	7
54	.65474	.75585	.66783	.74431	.68072	.73254	.69340	.72055	.70587	.70834	6
55	.65496	.75566	.66805	.74412	.68093	.73234	.69361	.72035	.70608	.70813	5
56	.65518	.75547	.66827	.74392	.68115	.73215	.69382	.72015	.70628	.70793	4
57	.65540	.75528	.66848	.74373	.68136	.73195	.69403	.71995	.70649	.70772	3
58	.65562	.75509	.66870	.74353	.68157	.73175	.69424	.71974	.70670	.70752	2
59	.65584	.75490	.66891	.74334	.68179	.73155	.69445	.71954	.70690	.70731	1
60	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	49°		48°		47°		46°		45°		

NATURAL TANGENTS AND COTANGENTS.

′	0°		1°		2°		3°		4°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.00000	Infin.	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	60
1	.00029	3437.75	.01775	56.3506	.03521	28.3994	.05270	18.9755	.07022	14.2411	59
2	.00058	1718.87	.01804	55.4415	.03550	28.1664	.05299	18.8711	.07051	14.1821	58
3	.00087	1145.92	.01833	54.5613	.03579	27.9372	.05328	18.7678	.07080	14.1235	57
4	.00116	859.436	.01862	53.7086	.03609	27.7117	.05357	18.6656	.07110	14.0655	56
5	.00145	687.549	.01891	52.8821	.03638	27.4899	.05387	18.5645	.07139	14.0079	55
6	.00175	572.957	.01920	52.0807	.03667	27.2715	.05416	18.4645	.07168	13.9507	54
7	.00204	491.106	.01949	51.3032	.03696	27.0566	.05445	18.3655	.07197	13.8940	53
8	.00233	429.718	.01978	50.5485	.03725	26.8450	.05474	18.2677	.07227	13.8378	52
9	.00262	381.971	.02007	49.8157	.03754	26.6367	.05503	18.1708	.07256	13.7821	51
10	.00291	343.774	.02036	49.1039	.03783	26.4316	.05533	18.0750	.07285	13.7267	50
11	.00320	312.521	.02066	48.4121	.03812	26.2296	.05562	17.9802	.07314	13.6719	49
12	.00349	286.478	.02095	47.7395	.03842	26.0307	.05591	17.8863	.07344	13.6174	48
13	.00378	264.441	.02124	47.0853	.03871	25.8348	.05620	17.7934	.07373	13.5634	47
14	.00407	245.552	.02153	46.4489	.03900	25.6418	.05649	17.7015	.07402	13.5098	46
15	.00436	229.182	.02182	45.8294	.03929	25.4517	.05678	17.6106	.07431	13.4566	45
16	.00465	214.858	.02211	45.2261	.03958	25.2644	.05708	17.5205	.07461	13.4039	44
17	.00495	202.219	.02240	44.6386	.03987	25.0798	.05737	17.4314	.07490	13.3515	43
18	.00524	190.984	.02269	44.0661	.04016	24.8978	.05766	17.3432	.07519	13.2996	42
19	.00553	180.932	.02298	43.5081	.04046	24.7185	.05795	17.2558	.07548	13.2480	41
20	.00582	171.885	.02328	42.9641	.04075	24.5418	.05824	17.1693	.07578	13.1969	40
21	.00611	163.700	.02357	42.4335	.04104	24.3675	.05854	17.0837	.07607	13.1461	39
22	.00640	156.259	.02386	41.9158	.04133	24.1957	.05883	16.9990	.07636	13.0958	38
23	.00669	149.465	.02415	41.4106	.04162	24.0263	.05912	16.9150	.07665	13.0458	37
24	.00698	143.237	.02444	40.9174	.04191	23.8593	.05941	16.8319	.07695	12.9962	36
25	.00727	137.507	.02473	40.4358	.04220	23.6945	.05970	16.7496	.07724	12.9469	35
26	.00756	132.219	.02502	39.9655	.04250	23.5321	.05999	16.6681	.07753	12.8981	34
27	.00785	127.321	.02531	39.5053	.04279	23.3718	.06029	16.5874	.07782	12.8496	33
28	.00815	122.774	.02560	39.0568	.04308	23.2137	.06058	16.5075	.07812	12.8014	32
29	.00844	118.540	.02589	38.6177	.04337	23.0577	.06087	16.4283	.07841	12.7536	31
30	.00873	114.589	.02619	38.1885	.04366	22.9038	.06116	16.3499	.07870	12.7062	30
31	.00902	110.892	.02648	37.7686	.04395	22.7519	.06145	16.2722	.07899	12.6591	29
32	.00931	107.426	.02677	37.3579	.04424	22.6020	.06175	16.1952	.07929	12.6124	28
33	.00960	104.171	.02706	36.9560	.04454	22.4541	.06204	16.1190	.07958	12.5660	27
34	.00989	101.107	.02735	36.5627	.04483	22.3081	.06233	16.0435	.07987	12.5199	26
35	.01018	98.2179	.02764	36.1776	.04512	22.1640	.06262	15.9687	.08017	12.4742	25
36	.01047	95.4895	.02793	35.8006	.04541	22.0217	.06291	15.8945	.08046	12.4288	24
37	.01076	92.9085	.02822	35.4313	.04570	21.8813	.06321	15.8211	.08075	12.3838	23
38	.01105	90.4633	.02851	35.0695	.04599	21.7426	.06350	15.7483	.08104	12.3390	22
39	.01135	88.1436	.02881	34.7151	.04628	21.6056	.06379	15.6762	.08134	12.2946	21
40	.01164	85.9398	.02910	34.3678	.04658	21.4704	.06408	15.6048	.08163	12.2505	20
41	.01193	83.8435	.02939	34.0273	.04687	21.3369	.06437	15.5340	.08192	12.2067	19
42	.01222	81.8470	.02968	33.6935	.04716	21.2049	.06467	15.4638	.08221	12.1632	18
43	.01251	79.9434	.02997	33.3662	.04745	21.0747	.06496	15.3943	.08251	12.1201	17
44	.01280	78.1263	.03026	33.0452	.04774	20.9460	.06525	15.3254	.08280	12.0772	16
45	.01309	76.3900	.03055	32.7303	.04803	20.8188	.06554	15.2571	.08309	12.0346	15
46	.01338	74.7292	.03084	32.4213	.04833	20.6932	.06584	15.1893	.08339	11.9923	14
47	.01367	73.1390	.03114	32.1181	.04862	20.5691	.06613	15.1222	.08368	11.9504	13
48	.01396	71.6151	.03143	31.8205	.04891	20.4465	.06642	15.0557	.08397	11.9087	12
49	.01425	70.1533	.03172	31.5284	.04920	20.3253	.06671	14.9898	.08427	11.8673	11
50	.01455	68.7501	.03201	31.2416	.04949	20.2056	.06700	14.9244	.08456	11.8262	10
51	.01484	67.4019	.03230	30.9599	.04978	20.0872	.06730	14.8596	.08485	11.7853	9
52	.01513	66.1055	.03259	30.6833	.05007	19.9702	.06759	14.7954	.08514	11.7448	8
53	.01542	64.8580	.03288	30.4116	.05037	19.8546	.06788	14.7317	.08544	11.7045	7
54	.01571	63.6567	.03317	30.1446	.05066	19.7403	.06817	14.6685	.08573	11.6645	6
55	.01600	62.4992	.03346	29.8823	.05095	19.6273	.06847	14.6059	.08602	11.6248	5
56	.01629	61.3829	.03376	29.6245	.05124	19.5156	.06876	14.5438	.08632	11.5853	4
57	.01658	60.3058	.03405	29.3711	.05153	19.4051	.06905	14.4823	.08661	11.5461	3
58	.01687	59.2659	.03434	29.1220	.05182	19.2959	.06934	14.4212	.08690	11.5072	2
59	.01716	58.2612	.03463	28.8771	.05212	19.1879	.06963	14.3607	.08720	11.4685	1
60	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	.08749	11.4301	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	89°		88°		87°		86°		85°		

NATURAL TANGENTS AND COTANGENTS.

′	5°		6°		7°		8°		9°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.08749	11.4301	.10510	9.51436	.12278	8.14435	.14054	7.11537	.15838	6.31375	60
1	.08778	11.3919	.10540	9.48781	.12308	8.12481	.14084	7.10038	.15868	6.30189	59
2	.08807	11.3540	.10569	9.46141	.12338	8.10536	.14113	7.08546	.15898	6.29007	58
3	.08837	11.3163	.10599	9.43515	.12367	8.08600	.14143	7.07059	.15928	6.27829	57
4	.08866	11.2789	.10629	9.40904	.12397	8.06674	.14173	7.05579	.15958	6.26655	56
5	.08895	11.2417	.10657	9.38307	.12426	8.04756	.14202	7.04105	.15988	6.25486	55
6	.08925	11.2048	.10687	9.35724	.12456	8.02848	.14232	7.02637	.16017	6.24321	54
7	.08954	11.1681	.10716	9.33155	.12485	8.00948	.14262	7.01174	.16047	6.23160	53
8	.08983	11.1316	.10746	9.30599	.12515	7.99058	.14291	6.99718	.16077	6.22003	52
9	.09013	11.0954	.10775	9.28054	.12544	7.97176	.14321	6.98268	.16107	6.20851	51
10	.09042	11.0594	.10805	9.25530	.12574	7.95302	.14351	6.96823	.16137	6.19703	50
11	.09071	11.0237	.10834	9.23016	.12603	7.93438	.14381	6.95385	.16167	6.18559	49
12	.09101	10.9882	.10863	9.20516	.12633	7.91582	.14410	6.93952	.16196	6.17419	48
13	.09130	10.9529	.10893	9.18028	.12662	7.89734	.14440	6.92525	.16226	6.16283	47
14	.09159	10.9178	.10922	9.15554	.12692	7.87895	.14470	6.91104	.16256	6.15151	46
15	.09189	10.8829	.10952	9.13093	.12722	7.86064	.14499	6.89688	.16286	6.14023	45
16	.09218	10.8483	.10981	9.10646	.12751	7.84242	.14529	6.88278	.16316	6.12899	44
17	.09247	10.8139	.11011	9.08211	.12781	7.82428	.14559	6.86874	.16346	6.11779	43
18	.09277	10.7797	.11040	9.05789	.12810	7.80622	.14588	6.85475	.16376	6.10664	42
19	.09306	10.7457	.11070	9.03379	.12840	7.78825	.14618	6.84082	.16405	6.09552	41
20	.09335	10.7119	.11099	9.00983	.12869	7.77035	.14648	6.82694	.16435	6.08444	40
21	.09365	10.6783	.11128	8.98598	.12899	7.75254	.14678	6.81312	.16465	6.07340	39
22	.09394	10.6450	.11158	8.96227	.12929	7.73480	.14707	6.79936	.16495	6.06240	38
23	.09423	10.6118	.11187	8.93867	.12958	7.71715	.14737	6.78564	.16525	6.05143	37
24	.09453	10.5789	.11217	8.91520	.12988	7.69957	.14767	6.77199	.16555	6.04051	36
25	.09482	10.5462	.11246	8.89185	.13017	7.68208	.14796	6.75838	.16585	6.02963	35
26	.09511	10.5136	.11276	8.86862	.13047	7.66466	.14826	6.74483	.16615	6.01878	34
27	.09541	10.4813	.11305	8.84551	.13076	7.64732	.14856	6.73133	.16645	6.00797	33
28	.09570	10.4491	.11335	8.82252	.13106	7.63005	.14886	6.71789	.16674	5.99720	32
29	.09600	10.4172	.11364	8.79964	.13136	7.61287	.14915	6.70450	.16704	5.98647	31
30	.09629	10.3854	.11394	8.77689	.13165	7.59575	.14945	6.69116	.16734	5.97576	30
31	.09658	10.3538	.11423	8.75425	.13195	7.57872	.14975	6.67787	.16764	5.96510	29
32	.09688	10.3224	.11452	8.73172	.13224	7.56176	.15005	6.66463	.16794	5.95448	28
33	.09717	10.2913	.11482	8.70931	.13254	7.54487	.15034	6.65144	.16824	5.94390	27
34	.09746	10.2602	.11511	8.68701	.13284	7.52806	.15064	6.63831	.16854	5.93335	26
35	.09776	10.2294	.11541	8.66482	.13313	7.51132	.15094	6.62523	.16884	5.92285	25
36	.09805	10.1988	.11570	8.64275	.13343	7.49465	.15124	6.61219	.16914	5.91236	24
37	.09834	10.1683	.11600	8.62078	.13372	7.47806	.15153	6.59921	.16944	5.90191	23
38	.09864	10.1381	.11629	8.59893	.13402	7.46154	.15183	6.58627	.16974	5.89151	22
39	.09893	10.1080	.11659	8.57718	.13432	7.44509	.15213	6.57339	.17004	5.88114	21
40	.09923	10.0780	.11688	8.55555	.13461	7.42871	.15243	6.56055	.17033	5.87080	20
41	.09952	10.0483	.11718	8.53402	.13491	7.41240	.15272	6.54777	.17063	5.86051	19
42	.09981	10.0187	.11747	8.51259	.13521	7.39616	.15302	6.53503	.17093	5.85024	18
43	.10011	9.98931	.11777	8.49128	.13550	7.37999	.15332	6.52234	.17123	5.84001	17
44	.10040	9.96007	.11806	8.47007	.13580	7.36389	.15362	6.50970	.17153	5.82982	16
45	.10069	9.93101	.11836	8.44896	.13609	7.34786	.15391	6.49710	.17183	5.81966	15
46	.10099	9.90211	.11865	8.42795	.13639	7.33190	.15421	6.48456	.17213	5.80953	14
47	.10128	9.87338	.11895	8.40705	.13669	7.31600	.15451	6.47206	.17243	5.79944	13
48	.10158	9.84482	.11924	8.38625	.13698	7.30018	.15481	6.45961	.17273	5.78938	12
49	.10187	9.81641	.11954	8.36555	.13728	7.28442	.15511	6.44720	.17303	5.77936	11
50	.10216	9.78817	.11983	8.34496	.13758	7.26873	.15540	6.43484	.17333	5.76937	10
51	.10246	9.76009	.12013	8.32446	.13787	7.25310	.15570	6.42253	.17363	5.75941	9
52	.10275	9.73217	.12042	8.30406	.13817	7.23754	.15600	6.41026	.17393	5.74949	8
53	.10305	9.70441	.12072	8.28376	.13846	7.22204	.15630	6.39804	.17423	5.73960	7
54	.10334	9.67680	.12101	8.26355	.13876	7.20661	.15660	6.38587	.17453	5.72974	6
55	.10363	9.64935	.12131	8.24345	.13906	7.19125	.15689	6.37374	.17483	5.71992	5
56	.10393	9.62205	.12160	8.22344	.13935	7.17594	.15719	6.36165	.17513	5.71013	4
57	.10422	9.59490	.12190	8.20352	.13965	7.16071	.15749	6.34961	.17543	5.70037	3
58	.10452	9.56791	.12219	8.18370	.13995	7.14553	.15779	6.33761	.17573	5.69064	2
59	.10481	9.54106	.12249	8.16398	.14024	7.13042	.15809	6.32566	.17603	5.68094	1
60	.10510	9.51436	.12278	8.14435	.14054	7.11537	.15838	6.31375	.17633	5.67128	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	84°		83°		82°		81°		80°		

Natural Tangents and Cotangents.

′	10°		11°		12°		13°		14°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.17633	5.67128	.19438	5.14455	.21256	4.70463	.23087	4.33148	.24933	4.01078	60
1	.17663	5.66165	.19468	5.13658	.21286	4.69791	.23117	4.32573	.24964	4.00582	59
2	.17693	5.65205	.19498	5.12862	.21316	4.69121	.23148	4.32001	.24995	4.00086	58
3	.17723	5.64248	.19529	5.12069	.21347	4.68452	.23179	4.31430	.25026	3.99592	57
4	.17753	5.63295	.19559	5.11279	.21377	4.67786	.23209	4.30860	.25056	3.99099	56
5	.17783	5.62344	.19589	5.10490	.21408	4.67121	.23240	4.30291	.25087	3.98607	55
6	.17813	5.61397	.19619	5.09704	.21438	4.66458	.23271	4.29724	.25118	3.98117	54
7	.17843	5.60452	.19649	5.08921	.21469	4.65797	.23301	4.29159	.25149	3.97627	53
8	.17873	5.59511	.19680	5.08139	.21499	4.65138	.23332	4.28595	.25180	3.97139	52
9	.17903	5.58573	.19710	5.07360	.21529	4.64480	.23363	4.28032	.25211	3.96651	51
10	.17933	5.57638	.19740	5.06584	.21560	4.63825	.23393	4.27471	.25242	3.96165	50
11	.17963	5.56706	.19770	5.05809	.21590	4.63171	.23424	4.26911	.25273	3.95680	49
12	.17993	5.55777	.19801	5.05037	.21621	4.62518	.23455	4.26352	.25304	3.95196	48
13	.18023	5 54851	.19831	5.04267	.21651	4.61868	.23485	4.25795	.25335	3.94713	47
14	.18053	5.53927	.19861	5.03499	.21682	4.61219	.23516	4.25239	.25366	3.94232	46
15	.18083	5.53007	.19891	5.02734	.21712	4.60572	.23547	4.24685	.25397	3.93751	45
16	.18113	5.52090	.19921	5.01971	.21743	4.59927	.23578	4.24132	.25428	3.93271	44
17	.18143	5.51176	.19952	5.01210	.21773	4.59283	.23608	4.23580	.25459	3.92793	43
18	.18173	5.50264	.19982	5.00451	.21804	4.58641	.23639	4.23030	.25490	3.92316	42
19	.18203	5.49356	.20012	4.99695	.21834	4.58001	.23670	4.22481	.25521	3.91839	41
20	.18233	5.48451	.20042	4.98940	.21864	4.57363	.23700	4.21933	.25552	3.91364	40
21	.18263	5.47548	.20073	4.98188	.21895	4.56726	.23731	4.21387	.25583	3.90890	39
22	.18293	5.46648	.20103	4.97438	.21925	4.56091	.23762	4.20842	.25614	3.90417	38
23	.18323	5.45751	.20133	4.96690	.21956	4.55458	.23793	4.20298	.25645	3.89945	37
24	.18353	5.44857	.20164	4.95945	.21986	4.54826	.23823	4.19756	.25676	3.89474	36
25	.18384	5.43966	.20194	4.95201	.22017	4.54196	.23854	4.19215	.25707	3.89004	35
26	.18414	5.43077	.20224	4.94460	.22047	4.53568	.23885	4.18675	.25738	3.88536	34
27	.18444	5.42192	.20254	4.93721	.22078	4.52941	.23916	4.18137	.25769	3.88068	33
28	.18474	5.41309	.20285	4.92984	.22108	4.52316	.23946	4.17600	.25800	3.87601	32
29	.18504	5.40429	.20315	4.92249	.22139	4.51693	.23977	4.17064	.25831	3.87136	31
30	.18534	5.39552	.20345	4.91516	.22169	4.51071	.24008	4.16530	.25862	3.86671	30
31	.18564	5.38677	.20376	4.90785	.22200	4.50451	.24039	4.15997	.25893	3.86208	29
32	.18594	5.37805	.20406	4.90056	.22231	4.49832	.24069	4.15465	.25924	3.85745	28
33	.18624	5.36936	.20436	4.89330	.22261	4.49215	.24100	4.14934	.25955	3.85284	27
34	.18654	5.36070	.20466	4.88605	.22292	4.48600	.24131	4.14405	.25986	3.84824	26
35	.18684	5.35206	.20497	4.87882	.22322	4.47986	.24162	4.13877	.26017	3.84364	25
36	.18714	5.34345	.20527	4.87162	.22353	4.47374	.24193	4.13350	.26048	3.83906	24
37	.18745	5.33487	.20557	4.86444	.22383	4.46764	.24223	4.12825	.26079	3.83449	23
38	.18775	5.32631	.20588	4.85727	.22414	4.46155	.24254	4.12301	.26110	3.82992	22
39	.18805	5.31778	.20618	4.85013	.22444	4.45548	.24285	4.11778	.26141	3.82537	21
40	.18835	5.30928	.20648	4.84300	.22475	4.44942	.24316	4.11256	.26172	3.82083	20
41	.18865	5.30080	.20679	4.83590	.22505	4.44338	.24347	4.10736	.26203	3.81630	19
42	.18895	5.29235	.20709	4.82882	.22536	4.43735	.24377	4.10216	.26235	3.81177	18
43	.18925	5.28393	.20739	4.82175	.22567	4.43134	.24408	4.09699	.26266	3.80726	17
44	.18955	5.27553	.20770	4.81471	.22597	4.42534	.24439	4.09182	.26297	3.80276	16
45	.18986	5.26715	.20800	4.80769	.22628	4.41936	.24470	4.08666	.26328	3.79827	15
46	.19016	5.25880	.20830	4.80068	.22658	4.41340	.24501	4.08152	.26359	3.79378	14
47	.19046	5.25048	.20861	4.79370	.22689	4.40745	.24532	4.07639	.26390	3.78931	13
48	.19076	5.24218	.20891	4.78673	.22719	4.40152	.24562	4.07127	.26421	3.78485	12
49	.19106	5.23391	.20921	4.77978	.22750	4.39560	.24593	4.06616	.26452	3.78040	11
50	.19136	5.22566	.20952	4.77286	.22781	4.38969	.24624	4.06107	.26483	3.77595	10
51	.19166	5.21744	.20982	4.76595	.22811	4.38381	.24655	4.05599	.26515	3.77152	9
52	.19197	5.20925	.21013	4.75906	.22842	4.37793	.24686	4.05092	.26546	3.76709	8
53	.19227	5.20107	.21043	4.75219	.22872	4.37207	.24717	4.04586	.26577	3.76268	7
54	.19257	5.19293	.21073	4.74534	.22903	4.36623	.24747	4.04081	.26608	3.75828	6
55	.19287	5.18480	.21104	4.73851	.22934	4.36040	.24778	4.03578	.26639	3.75388	5
56	.19317	5.17671	.21134	4.73170	.22964	4.35459	.24809	4.03076	.26670	3.74950	4
57	.19347	5.16863	.21164	4.72490	.22995	4.34879	.24840	4.02574	.26701	3.74512	3
58	.19378	5.16058	.21195	4.71813	.23026	4.34300	.24871	4.02074	.26733	3.74075	2
59	.19408	5.15256	.21225	4.71137	.23056	4.33723	.24902	4.01576	.26764	3.73640	1
60	.19438	5.14455	.21256	4.70463	.23087	4.33148	.24933	4.01078	.26795	3.73205	0
′		Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
		78°		77°		76°		75			

NATURAL TANGENTS AND COTANGENTS.

′	15°		16°		17°		18°		19°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.26795	3.73205	.28675	3.48741	.30573	3.27085	.32492	3.07768	.34433	2.90421	60
1	.26826	3.72771	.28706	3.48359	.30605	3.26745	.32524	3.07464	.34465	2.90147	59
2	.26857	3.72338	.28738	3.47977	.30637	3.26406	.32556	3.07160	.34498	2.89873	58
3	.26888	3.71907	.28769	3.47596	.30669	3.26067	.32588	3.06857	.34530	2.89600	57
4	.26920	3.71476	.28800	3.47216	.30700	3.25729	.32621	3.06554	.34563	2.89327	56
5	.26951	3.71046	.28832	3.46837	.30732	3.25392	.32653	3.06252	.34596	2.89055	55
6	.26982	3.70616	.28864	3.46458	.30764	3.25055	.32685	3.05950	.34628	2.88783	54
7	.27013	3.70188	.28895	3.46080	.30796	3.24719	.32717	3.05649	.34661	2.88511	53
8	.27044	3.69761	.28927	3.45703	.30828	3.24383	.32749	3.05349	.34693	2.88240	52
9	.27076	3.69335	.28958	3.45327	.30860	3.24049	.32782	3.05049	.34726	2.87970	51
10	.27107	3.68909	.28990	3.44951	.30891	3.23714	.32814	3.04749	.34758	2.87700	50
11	.27138	3.68485	.29021	3.44576	.30923	3.23381	.32846	3.04450	.34791	2.87430	49
12	.27169	3.68061	.29053	3.44202	.30955	3.23048	.32878	3.04152	.34824	2.87161	48
13	.27201	3.67638	.29084	3.43827	.30987	3.22715	.32911	3.03854	.34856	2.86892	47
14	.27232	3.67217	.29116	3.43456	.31019	3.22384	.32943	3.03556	.34889	2.86624	46
15	.27263	3.66796	.29147	3.43084	.31051	3.22053	.32975	3.03260	.34922	2.86356	45
16	.27294	3.66376	.29179	3.42713	.31083	3.21722	.33007	3.02963	.34954	2.86089	44
17	.27326	3.65957	.29210	3.42343	.31115	3.21392	.33040	3.02667	.34987	2.85822	43
18	.27357	3.65538	.29242	3.41973	.31147	3.21063	.33072	3.02372	.35020	2.85555	42
19	.27388	3.65121	.29274	3.41604	.31178	3.20734	.33104	3.02077	.35052	2.85289	41
20	.27419	3.64705	.29305	3.41236	.31210	3.20406	.33136	3.01783	.35085	2.85023	40
21	.27451	3.64289	.29337	3.40869	.31242	3.20079	.33169	3.01489	.35118	2.84758	39
22	.27482	3.63874	.29368	3.40502	.31274	3.19752	.33201	3.01196	.35150	2.84494	38
23	.27513	3.63461	.29400	3.40136	.31306	3.19426	.33233	3.00903	.35183	2.84229	37
24	.27545	3.63048	.29432	3.39771	.31338	3.19100	.33266	3.00611	.35216	2.83965	36
25	.27576	3.62636	.29463	3.39406	.31370	3.18775	.33298	3.00319	.35248	2.83702	35
26	.27607	3.62224	.29495	3.39042	.31402	3.18451	.33330	3.00028	.35281	2.83439	34
27	.27638	3.61814	.29526	3.38679	.31434	3.18127	.33363	2.99738	.35314	2.83176	33
28	.27670	3.61405	.29558	3.38317	.31466	3.17804	.33395	2.99447	.35346	2.82914	32
29	.27701	3.60996	.29590	3.37955	.31498	3.17481	.33427	2.99158	.35379	2.82653	31
30	.27732	3.60588	.29621	3.37594	.31530	3.17159	.33460	2.98868	.35412	2.82391	30
31	.27764	3.60181	.29653	3.37234	.31562	3.16838	.33492	2.98580	.35445	2.82130	29
32	.27795	3.59775	.29685	3.36875	.31594	3.16517	.33524	2.98292	.35477	2.81870	28
33	.27826	3.59370	.29716	3.36516	.31626	3.16197	.33557	2.98004	.35510	2.81610	27
34	.27858	3.58966	.29748	3.36158	.31658	3.15877	.33589	2.97717	.35543	2.81350	26
35	.27889	3.58562	.29780	3.35800	.31690	3.15558	.33621	2.97430	.35576	2.81091	25
36	.27921	3.58160	.29811	3.35443	.31722	3.15240	.33654	2.97144	.35608	2.80833	24
37	.27952	3.57758	.29843	3.35087	.31754	3.14922	.33686	2.96858	.35641	2.80574	23
38	.27983	3.57357	.29875	3.34732	.31786	3.14605	.33718	2.96573	.35674	2.80316	22
39	.28015	3.56957	.29906	3.34377	.31818	3.14288	.33751	2.96288	.35707	2.80059	21
40	.28046	3.56557	.29938	3.34023	.31850	3.13972	.33783	2.96004	.35740	2.79802	20
41	.28077	3.56159	.29970	3.33670	.31882	3.13656	.33816	2.95721	.35772	2.79545	19
42	.28109	3.55761	.30001	3.33317	.31914	3.13341	.33848	2.95437	.35805	2.79289	18
43	.28140	3.55364	.30033	3.32965	.31946	3.13027	.33881	2.95155	.35838	2.79033	17
44	.28172	3.54968	.30065	3.32614	.31978	3.12713	.33913	2.94872	.35871	2.78778	16
45	.28203	3.54573	.30097	3.32264	.32010	3.12400	.33945	2.94591	.35904	2.78523	15
46	.28234	3.54179	.30128	3.31914	.32042	3.12087	.33978	2.94309	.35937	2.78269	14
47	.28266	3.53785	.30160	3.31565	.32074	3.11775	.34010	2.94028	.35969	2.78014	13
48	.28297	3.53393	.30192	3.31216	.32106	3.11464	.34043	2.93748	.36002	2.77761	12
49	.28329	3.53001	.30224	3.30868	.32139	3.11153	.34075	2.93468	.36035	2.77507	11
50	.28360	3.52609	.30255	3.30521	.32171	3.10842	.34108	2.93189	.36068	2.77254	10
51	.28391	3.52219	.30287	3.30174	.32203	3.10532	.34140	2.92910	.36101	2.77002	9
52	.28423	3.51829	.30319	3.29829	.32235	3.10223	.34173	2.92632	.36134	2.76750	8
53	.28454	3.51441	.30351	3.29483	.32267	3.09914	.34205	2.92354	.36167	2.76498	7
54	.28486	3.51053	.30382	3.29139	.32299	3.09606	.34238	2.92076	.36199	2.76247	6
55	.28517	3.50666	.30414	3.28795	.32331	3.09298	.34270	2.91799	.36232	2.75996	5
56	.28549	3.50279	.30446	3.28452	.32363	3.08991	.34303	2.91523	.36265	2.75746	4
57	.28580	3.49894	.30478	3.28109	.32396	3.08685	.34335	2.91246	.36298	2.75496	3
58	.28612	3.49509	.30509	3.27767	.32428	3.08379	.34368	2.90971	.36331	2.75246	2
59	.28643	3.49125	.30541	3.27426	.32460	3.08073	.34400	2.90696	.36364	2.74997	1
60	.28675	3.48741	.30573	3.27085	.32492	3.07768	.34433	2.90421	.36397	2.74748	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	74°		73°		72°		71°		70°		

Natural Tangents and Cotangents.

	20°		21°		22°		23°		24°		
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.36397	2.74748	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604	60
1	.36430	2.74499	.38420	2.60283	.40436	2.47302	.42482	2.35395	.44558	2.24428	59
2	.36463	2.74251	.38453	2.60057	.40470	2.47095	.42516	2.35205	.44593	2.24252	58
3	.36496	2.74004	.38487	2.59831	.40504	2.46888	.42551	2.35015	.44627	2.24077	57
4	.36529	2.73756	.38520	2.59606	.40538	2.46682	.42585	2.34825	.44662	2.23902	56
5	.36562	2.73509	.38553	2.59381	.40572	2.46476	.42619	2.34636	.44697	2.23727	55
6	.36595	2.73263	.38587	2.59156	.40606	2.46270	.42654	2.34447	.44732	2.23551	54
7	.36628	2.73017	.38620	2.58932	.40640	2.46065	.42688	2.34258	.44767	2.23378	53
8	.36661	2.72771	.38654	2.58708	.40674	2.45860	.42722	2.34069	.44802	2.23204	52
9	.36694	2.72526	.38687	2.58484	.40707	2.45655	.42757	2.33881	.44837	2.23030	51
10	.36727	2.72281	.38721	2.58261	.40741	2.45451	.42791	2.33693	.44872	2.22857	50
11	.36760	2.72036	.38754	2.58038	.40775	2.45246	.42826	2.33505	.44907	2.22683	49
12	.36793	2.71792	.38787	2.57815	.40809	2.45043	.42860	2.33317	.44942	2.22510	48
13	.36826	2.71548	.38821	2.57593	.40843	2.44839	.42894	2.33130	.44977	2.22337	47
14	.36859	2.71305	.38854	2.57371	.40877	2.44636	.42929	2.32943	.45012	2.22164	46
15	.36892	2.71062	.38888	2.57150	.40911	2.44433	.42963	2.32756	.45047	2.21992	45
16	.36925	2.70819	.38921	2.56928	.40945	2.44230	.42998	2.32570	.45082	2.21819	44
17	.36958	2.70577	.38955	2.56707	.40979	2.44027	.43032	2.32383	.45117	2.21647	43
18	.36991	2.70335	.38988	2.56487	.41013	2.43825	.43067	2.32197	.45152	2.21475	42
19	.37024	2.70094	.39022	2.56266	.41047	2.43623	.43101	2.32012	.45187	2.21304	41
20	.37057	2.69853	.39055	2.56046	.41081	2.43422	.43136	2.31826	.45222	2.21132	40
21	.37090	2.69612	.39089	2.55827	.41115	2.43220	.43170	2.31641	.45257	2.20961	39
22	.37123	2.69371	.39122	2.55608	.41149	2.43019	.43205	2.31456	.45292	2.20790	38
23	.37157	2.69131	.39156	2.55389	.41183	2.42819	.43239	2.31271	.45327	2.20619	37
24	.37190	2.68892	.39189	2.55170	.41217	2.42618	.43274	2.31086	.45362	2.20449	36
25	.37223	2.68653	.39223	2.54952	.41251	2.42418	.43308	2.30902	.45397	2.20278	35
26	.37256	2.68414	.39257	2.54734	.41285	2.42218	.43343	2.30718	.45432	2.20108	34
27	.37289	2.68175	.39290	2.54516	.41319	2.42019	.43378	2.30534	.45467	2.19938	33
28	.37322	2.67937	.39324	2.54299	.41353	2.41819	.43412	2.30349	.45502	2.19769	32
29	.37355	2.67700	.39357	2.54082	.41387	2.41620	.43447	2.30167	.45538	2.19599	31
30	.37388	2.67462	.39391	2.53865	.41421	2.41421	.43481	2.29984	.45573	2.19430	30
31	.37422	2.67225	.39425	2.53648	.41455	2.41223	.43516	2.29801	.45608	2.19261	29
32	.37455	2.66989	.39458	2.53432	.41490	2.41025	.43550	2.29619	.45643	2.19092	28
33	.37488	2.66752	.39492	2.53217	.41524	2.40827	.43585	2.29437	.45678	2.18923	27
34	.37521	2.66516	.39526	2.53001	.41558	2.40629	.43620	2.29254	.45713	2.18755	26
35	.37554	2.66281	.39559	2.52786	.41592	2.40432	.43654	2.29071	.45748	2.18587	25
36	.37588	2.66046	.39593	2.52571	.41626	2.40235	.43689	2.28891	.45784	2.18419	24
37	.37621	2.65811	.39626	2.52357	.41660	2.40038	.43724	2.28710	.45819	2.18251	23
38	.37654	2.65576	.39660	2.52142	.41694	2.39841	.43758	2.28528	.45854	2.18084	22
39	.37687	2.65342	.39694	2.51929	.41728	2.39645	.43793	2.28348	.45889	2.17916	21
40	.37720	2.65109	.39727	2.51715	.41763	2.39449	.43828	2.28167	.45924	2.17749	20
41	.37754	2.64875	.39761	2.51502	.41797	2.39253	.43862	2.27987	.45960	2.17582	19
42	.37787	2.64642	.39795	2.51289	.41831	2.39058	.43897	2.27806	.45995	2.17416	18
43	.37820	2.64410	.39828	2.51076	.41865	2.38863	.43932	2.27626	.46030	2.17249	17
44	.37853	2.64177	.39862	2.50864	.41899	2.38668	.43966	2.27447	.46065	2.17083	16
45	.37887	2.63945	.39896	2.50652	.41933	2.38473	.44001	2.27267	.46101	2.16917	15
46	.37920	2.63714	.39930	2.50440	.41968	2.38279	.44036	2.27088	.46136	2.16751	14
47	.37953	2.63483	.39963	2.50229	.42002	2.38084	.44071	2.26909	.46171	2.16585	13
48	.37986	2.63252	.39997	2.50018	.42036	2.37891	.44105	2.26730	.46206	2.16420	12
49	.38020	2.63021	.40031	2.49807	.42070	2.37697	.44140	2.26552	.46242	2.16255	11
50	.38053	2.62791	.40065	2.49597	.42105	2.37504	.44175	2.26374	.46277	2.16090	10
51	.38086	2.62561	.40098	2.49386	.42139	2.37311	.44210	2.26196	.46312	2.15925	9
52	.38120	2.62332	.40132	2.49177	.42173	2.37118	.44244	2.26018	.46348	2.15760	8
53	.38153	2.62103	.40166	2.48967	.42207	2.36925	.44279	2.25840	.46383	2.15596	7
54	.38186	2.61874	.40200	2.48758	.42242	2.36733	.44314	2.25663	.46418	2.15432	6
55	.38220	2.61646	.40234	2.48549	.42276	2.36541	.44349	2.25486	.46454	2.15268	5
56	.38253	2.61418	.40267	2.48340	.42310	2.36349	.44384	2.25309	.46489	2.15104	4
57	.38286	2.61190	.40301	2.48132	.42345	2.36158	.44418	2.25132	.46525	2.14940	3
58	.38320	2.60963	.40335	2.47924	.42379	2.35967	.44453	2.24956	.46560	2.14777	2
59	.38353	2.60736	.40369	2.47716	.42413	2.35776	.44488	2.24780	.46595	2.14614	1
60	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604	.46631	2.14451	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	69°		68°		67°		66°		65°		

Natural Tangents and Cotangents.

′	25°		26°		27°		28°		29°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.46631	2.14451	.48773	2.05030	.50953	1.96261	.53171	1.88073	.55431	1.80405	60
1	.46666	2.14288	.48809	2.04879	.50989	1.96120	.53208	1.87941	.55469	1.80281	59
2	.46702	2.14125	.48845	2.04728	.51026	1.95979	.53246	1.87809	.55507	1.80158	58
3	.46737	2.13963	.48881	2.04577	.51063	1.95838	.53283	1.87677	.55545	1.80034	57
4	.46772	2.13801	.48917	2.04426	.51099	1.95698	.53320	1.87546	.55583	1.79911	56
5	.46808	2.13639	.48953	2.04276	.51136	1.95557	.53358	1.87415	.55621	1.79788	55
6	.46843	2.13477	.48989	2.04125	.51173	1.95417	.53395	1.87283	.55659	1.79665	54
7	.46879	2.13316	.49026	2.03975	.51209	1.95277	.53432	1.87152	.55697	1.79542	53
8	.46914	2.13154	.49062	2.03825	.51246	1.95137	.53470	1.87021	.55736	1.79419	52
9	.46950	2.12993	.49098	2.03675	.51283	1.94997	.53507	1.86891	.55774	1.79296	51
10	.46985	2.12832	.49134	2.03526	.51319	1.94858	.53545	1.86760	.55812	1.79174	50
11	.47021	2.12671	.49170	2.03376	.51356	1.94718	.53582	1.86630	.55850	1.79051	49
12	.47056	2.12511	.49206	2.03227	.51393	1.94579	.53620	1.86499	.55888	1.78929	48
13	.47092	2.12350	.49242	2.03078	.51430	1.94440	.53657	1.86369	.55926	1.78807	47
14	.47128	2.12190	.49278	2.02929	.51467	1.94301	.55694	1.86239	.55964	1.78685	46
15	.47163	2.12030	.49315	2.02780	.51503	1.94162	.53732	1.86109	.56003	1.78563	45
16	.47199	2.11871	.49351	2.02631	.51540	1.94023	.53769	1.85979	.56041	1.78441	44
17	.47234	2.11711	.49387	2.02483	.51577	1.93885	.53807	1.85850	.56079	1.78319	43
18	.47270	2.11552	.49423	2.02335	.51614	1.93746	.53844	1.85720	.56117	1.78198	42
19	.47305	2.11392	.49459	2.02187	.51651	1.93608	.53882	1.85591	.56156	1.78077	41
20	.47341	2.11233	.49495	2.02039	.51688	1.93470	.53920	1.85462	.56194	1.77955	40
21	.47377	2.11075	.49532	2.01891	.51724	1.93332	.53957	1.85333	.56232	1.77834	39
22	.47412	2.10916	.49568	2.01743	.51761	1.93195	.53995	1.85204	.56270	1.77713	38
23	.47448	2.10758	.49604	2.01596	.51798	1.93057	.54032	1.85075	.56309	1.77592	37
24	.47483	2.10600	.49640	2.01449	.51835	1.92920	.54070	1.84946	.56347	1.77471	36
25	.47519	2.10442	.49677	2.01302	.51872	1.92782	.54107	1.84818	.56385	1.77351	35
26	.47555	2.10284	.49713	2.01155	.51909	1.92645	.54145	1.84689	.56424	1.77230	34
27	.47590	2.10126	.49749	2.01008	.51946	1.92508	.54183	1.84561	.56462	1.77110	33
28	.47626	2.09969	.49786	2.00862	.51983	1.92371	.54220	1.84433	.56501	1.76990	32
29	.47662	2.09811	.49822	2.00715	.52020	1.92235	.54258	1.84305	.56539	1.76869	31
30	.47698	2.09654	.49858	2.00569	.52057	1.92098	.54296	1.84177	.56577	1.76749	30
31	.47733	2.09498	.49894	2.00423	.52094	1.91962	.54333	1.84049	.56616	1.76629	29
32	.47769	2.09341	.49931	2.00277	.52131	1.91826	.54371	1.83922	.56654	1.76510	28
33	.47805	2.09184	.49967	2.00131	.52168	1.91690	.54409	1.83794	.56693	1.76390	27
34	.47840	2.09028	.50004	1.99986	.52205	1.91554	.54446	1.83667	.56731	1.76271	26
35	.47876	2.08872	.50040	1.99841	.52242	1.91418	.54484	1.83540	.56769	1.76151	25
36	.47912	2.08716	.50076	1.99695	.52279	1.91282	.54522	1.83413	.56808	1.76032	24
37	.47948	2.08560	.50113	1.99550	.52316	1.91147	.54560	1.83286	.56846	1.75913	23
38	.47984	2.08405	.50149	1.99405	.52353	1.91012	.54597	1.83159	.56885	1.75794	22
39	.48019	2.08250	.50185	1.99261	.52390	1.90876	.54635	1.83033	.56923	1.75675	21
40	.48055	2.08094	.50222	1.99116	.52427	1.90741	.54673	1.82906	.56962	1.75556	20
41	.48091	2.07939	.50258	1.98972	.52464	1.90607	.54711	1.82780	.57000	1.75437	19
42	.48127	2.07785	.50295	1.98828	.52501	1.90472	.54748	1.82654	.57039	1.75319	18
43	.48163	2.07630	.50331	1.98684	.52538	1.90337	.54786	1.82528	.57078	1.75200	17
44	.48198	2.07476	.50368	1.98540	.52575	1.90203	.54824	1.82402	.57116	1.75082	16
45	.48234	2.07321	.50404	1.98396	.52613	1.90069	.54862	1.82276	.57155	1.74964	15
46	.48270	2.07167	.50441	1.98253	.52650	1.89935	.54900	1.82150	.57193	1.74846	14
47	.48306	2.07014	.50477	1.98110	.52687	1.89801	.54938	1.82025	.57232	1.74728	13
48	.48342	2.06860	.50514	1.97966	.52724	1.89667	.54975	1.81899	.57271	1.74610	12
49	.48378	2.06707	.50550	1.97823	.52761	1.89533	.55013	1.81774	.57309	1.74492	11
50	.48414	2.06553	.50587	1.97681	.52798	1.89400	.55051	1.81649	.57348	1.74375	10
51	.48450	2.06400	.50623	1.97538	.52836	1.89266	.55089	1.81524	.57386	1.74257	9
52	.48486	2.06247	.50660	1.97395	.52873	1.89133	.55127	1.81399	.57425	1.74140	8
53	.48521	2.06094	.50696	1.97253	.52910	1.89000	.55165	1.81274	.57464	1.74022	7
54	.48557	2.05942	.50733	1.97111	.52947	1.88867	.55203	1.81150	.57503	1.73905	6
55	.48593	2.05789	.50769	1.96969	.52985	1.88734	.55241	1.81025	.57541	1.73788	5
56	.48629	2.05637	.50806	1.96827	.53022	1.88602	.55279	1.80901	.57580	1.73671	4
57	.48665	2.05485	.50843	1.96685	.53059	1.88469	.55317	1.80777	.57619	1.73555	3
58	.48701	2.05333	.50879	1.96544	.53096	1.88337	.55355	1.80653	.57657	1.73438	2
59	.48737	2.05182	.50916	1.96402	.53134	1.88205	.55393	1.80529	.57696	1.73321	1
60	.48773	2.05030	.50953	1.96261	.53171	1.88073	.55431	1.80405	.57735	1.73205	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	64°		63°		62°		61°		60°		

Natural Tangents and Cotangents.

′	30°		31°		32°		33°		34°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.57735	1.73205	.60086	1.66428	.62487	1.60033	.64941	1.53986	.67451	1.48256	60
1	.57774	1.73089	.60126	1.66318	.62527	1.59930	.64982	1.53888	.67493	1.48163	59
2	.57813	1.72973	.60165	1.66209	.62568	1.59826	.65024	1.53791	.67536	1.48070	58
3	.57851	1.72857	.60205	1.66099	.62608	1.59723	.65065	1.53693	.67578	1.47977	57
4	.57890	1.72741	.60245	1.65990	.62649	1.59620	.65106	1.53595	.67620	1.47885	56
5	.57929	1.72625	.60284	1.65881	.62689	1.59517	.65148	1.53497	.67663	1.47792	55
6	.57968	1.72509	.60324	1.65772	.62730	1.59414	.65189	1.53400	.67705	1.47699	54
7	.58007	1.72393	.60364	1.65663	.62770	1.59311	.65231	1.53302	.67748	1.47607	53
8	.58046	1.72278	.60403	1.65554	.62811	1.59208	.65272	1.53205	.67790	1.47514	52
9	.58085	1.72163	.60443	1.65445	.62852	1.59105	.65314	1.53107	.67832	1.47422	51
10	.58124	1.72047	.60483	1.65337	.62892	1.59002	.65355	1.53010	.67875	1.47330	50
11	.58162	1.71932	.60522	1.65228	.62933	1.58900	.65397	1.52913	.67917	1.47238	49
12	.58201	1.71817	.60562	1.65120	.62973	1.58797	.65438	1.52816	.67960	1.47146	48
13	.58240	1.71702	.60602	1.65011	.63014	1.58695	.65480	1.52719	.68002	1.47053	47
14	.58279	1.71588	.60642	1.64903	.63055	1.58593	.65521	1.52622	.68045	1.46962	46
15	.58318	1.71473	.60681	1.64795	.63095	1.58490	.65563	1.52525	.68088	1.46870	45
16	.58357	1.71358	.60721	1.64687	.63136	1.58388	.65604	1.52429	.68130	1.46778	44
17	.58396	1.71244	.60761	1.64579	.63177	1.58286	.65646	1.52332	.68173	1.46686	43
18	.58435	1.71129	.60801	1.64471	.63217	1.58184	.65688	1.52235	.68215	1.46595	42
19	.58474	1.71015	.60841	1.64363	.63258	1.58083	.65729	1.52139	.68258	1.46503	41
20	.58513	1.70901	.60881	1.64256	.63299	1.57981	.65771	1.52043	.68301	1.46411	40
21	.58552	1.70787	.60921	1.64148	.63340	1.57879	.65813	1.51946	.68343	1.46320	39
22	.58591	1.70673	.60960	1.64041	.63380	1.57778	.65854	1.51850	.68386	1.46229	38
23	.58631	1.70560	.61000	1.63934	.63421	1.57676	.65896	1.51754	.68429	1.46137	37
24	.58670	1.70446	.61040	1.63826	.63462	1.57575	.65938	1.51658	.68471	1.46046	36
25	.58709	1.70332	.61080	1.63719	.63503	1.57474	.65980	1.51562	.68514	1.45955	35
26	.58748	1.70219	.61120	1.63612	.63544	1.57372	.66021	1.51466	.68557	1.45864	34
27	.58787	1.70106	.61160	1.63505	.63584	1.57271	.66063	1.51370	.68600	1.45773	33
28	.58826	1.69992	.61200	1.63398	.63625	1.57170	.66105	1.51275	.68642	1.45682	32
29	.58865	1.69879	.61240	1.63292	.63666	1.57069	.66147	1.51179	.68685	1.45592	31
30	.58905	1.69766	.61280	1.63185	.63707	1.56969	.66189	1.51084	.68728	1.45501	30
31	.58944	1.69653	.61320	1.63079	.63748	1.56868	.66230	1.50988	.68771	1.45410	29
32	.58983	1.69541	.61360	1.62972	.63789	1.56767	.66272	1.50893	.68814	1.45320	28
33	.59022	1.69428	.61400	1.62866	.63830	1.56667	.66314	1.50797	.68857	1.45229	27
34	.59061	1.69316	.61440	1.62760	.63871	1.56566	.66356	1.50702	.68900	1.45139	26
35	.59101	1.69203	.61480	1.62654	.63912	1.56466	.66398	1.50607	.68942	1.45049	25
36	.59140	1.69091	.61520	1.62548	.63953	1.56366	.66440	1.50512	.68985	1.44958	24
37	.59179	1.68979	.61561	1.62442	.63994	1.56265	.66482	1.50417	.69028	1.44868	23
38	.59218	1.68866	.61601	1.62336	.64035	1.56165	.66524	1.50322	.69071	1.44778	22
39	.59258	1.68754	.61641	1.62230	.64076	1.56065	.66566	1.50228	.69114	1.44688	21
40	.59297	1.68643	.61681	1.62125	.64117	1.55966	.66608	1.50133	.69157	1.44598	20
41	.59336	1.68531	.61721	1.62019	.64158	1.55866	.66650	1.50038	.69200	1.44508	19
42	.59376	1.68419	.61761	1.61914	.64199	1.55766	.66692	1.49944	.69243	1.44418	18
43	.59415	1.68308	.61801	1.61808	.64240	1.55666	.66734	1.49849	.69286	1.44329	17
44	.59454	1.68196	.61842	1.61701	.64281	1.55567	.66776	1.49755	.69329	1.44239	16
45	.59494	1.68085	.61882	1.61598	.64322	1.55467	.66818	1.49661	.69372	1.44149	15
46	.59533	1.67974	.61922	1.61493	.64363	1.55368	.66860	1.49566	.69416	1.44060	14
47	.59573	1.67863	.61962	1.61388	.64404	1.55269	.66902	1.49472	.69459	1.43970	13
48	.59612	1.67752	.62003	1.61283	.64446	1.55170	.66944	1.49378	.69502	1.43881	12
49	.59651	1.67641	.62043	1.61179	.64487	1.55071	.66986	1.49284	.69545	1.43792	11
50	.59691	1.67530	.62083	1.61074	.64528	1.54972	.67028	1.49190	.69588	1.43703	10
51	.59730	1.67419	.62124	1.60970	.64569	1.54873	.67071	1.49097	.69631	1.43614	9
52	.59770	1.67309	.62164	1.60865	.64610	1.54774	.67113	1.49003	.69675	1.43525	8
53	.59809	1.67198	.62204	1.60761	.64652	1.54675	.67155	1.48909	.69718	1.43436	7
54	.59849	1.67088	.62245	1.60657	.64693	1.54576	.67197	1.48816	.69761	1.43347	6
55	.59888	1.66978	.62285	1.60553	.64734	1.54478	.67239	1.48722	.69804	1.43258	5
56	.59928	1.66867	.62325	1.60449	.64775	1.54379	.67282	1.48629	.69847	1.43169	4
57	.59967	1.66757	.62366	1.60345	.64817	1.54281	.67324	1.48536	.69891	1.43080	3
58	.60007	1.66647	.62406	1.60241	.64858	1.54183	.67366	1.48442	.69934	1.42992	2
59	.60046	1.66538	.62446	1.60137	.64899	1.54085	.67409	1.48349	.69977	1.42903	1
60	.60086	1.66428	.62487	1.60033	.64941	1.53986	.67451	1.48256	.70021	1.42815	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
			58°		57°		56°		55°		

NATURAL TANGENTS AND COTANGENTS.

′	35°		36°		37°		38°		39°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.70021	1.42815	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490	60
1	.70064	1.42726	.72699	1.37554	.75401	1.32624	.78175	1.27917	.81027	1.23416	59
2	.70107	1.42638	.72743	1.37470	.75447	1.32544	.78222	1.27841	.81075	1.23343	58
3	.70151	1.42550	.72788	1.37386	.75492	1.32464	.78269	1.27764	.81123	1.23270	57
4	.70194	1.42462	.72832	1.37302	.75538	1.32384	.78316	1.27688	.81171	1.23196	56
5	.70238	1.42374	.72877	1.37218	.75584	1.32304	.78363	1.27611	.81220	1.23123	55
6	.70281	1.42286	.72921	1.37134	.75629	1.32224	.78410	1.27535	.81268	1.23050	54
7	.70325	1.42198	.72966	1.37050	.75675	1.32144	.78457	1.27458	.81316	1.22977	53
8	.70368	1.42110	.73010	1.36967	.75721	1.32064	.78504	1.27382	.81364	1.22904	52
9	.70412	1.42022	.73055	1.36883	.75767	1.31984	.78551	1.27306	.81413	1.22831	51
10	.70455	1.41934	.73100	1.36800	.75812	1.31904	.78598	1.27230	.81461	1.22758	50
11	.70499	1.41847	.73144	1.36716	.75858	1.31825	.78645	1.27153	.81510	1.22685	49
12	.70542	1.41759	.73189	1.36633	.75904	1.31745	.78692	1.27077	.81558	1.22612	48
13	.70586	1.41672	.73234	1.36549	.75950	1.31666	.78739	1.27001	.81606	1.22539	47
14	.70629	1.41584	.73278	1.36466	.75996	1.31586	.78786	1.26925	.81655	1.22467	46
15	.70673	1.41497	.73323	1.36383	.76042	1.31507	.78834	1.26849	.81703	1.22394	45
16	.70717	1.41409	.73368	1.36300	.76088	1.31427	.78881	1.26774	.81752	1.22321	44
17	.70760	1.41322	.73413	1.36217	.76134	1.31348	.78928	1.26698	.81800	1.22249	43
18	.70804	1.41235	.73457	1.36134	.76180	1.31269	.78975	1.26622	.81849	1.22176	42
19	.70848	1.41148	.73502	1.36051	.76226	1.31190	.79022	1.26546	.81898	1.22104	41
20	.70891	1.41061	.73547	1.35968	.76272	1.31110	.79070	1.26471	.81946	1.22031	40
21	.70935	1.40974	.73592	1.35885	.76318	1.31031	.79117	1.26395	.81995	1.21959	39
22	.70979	1.40887	.73637	1.35802	.76364	1.30952	.79164	1.26319	.82044	1.21886	38
23	.71023	1.40800	.73681	1.35719	.76410	1.30873	.79212	1.26244	.82092	1.21814	37
24	.71066	1.40714	.73726	1.35637	.76456	1.30795	.79259	1.26169	.82141	1.21742	36
25	.71110	1.40627	.73771	1.35554	.76502	1.30716	.79306	1.26093	.82190	1.21670	35
26	.71154	1.40540	.73816	1.35472	.76548	1.30637	.79354	1.26018	.82238	1.21598	34
27	.71198	1.40454	.73861	1.35389	.76594	1.30558	.79401	1.25943	.82287	1.21526	33
28	.71242	1.40367	.73906	1.35307	.76640	1.30480	.79449	1.25867	.82336	1.21454	32
29	.71285	1.40281	.73951	1.35224	.76686	1.30401	.79496	1.25792	.82385	1.21382	31
30	.71329	1.40195	.73996	1.35142	.76733	1.30323	.79544	1.25717	.82434	1.21310	30
31	.71373	1.40109	.74041	1.35060	.76779	1.30244	.77591	1.25642	.82483	1.21238	29
32	.71417	1.40022	.74086	1.34978	.76825	1.30166	.79639	1.25567	.82531	1.21166	28
33	.71461	1.39936	.74131	1.34896	.76871	1.30087	.79686	1.25492	.82580	1.21094	27
34	.71505	1.39850	.74176	1.34814	.76918	1.30009	.79734	1.25417	.82629	1.21023	26
35	.71549	1.39764	.74221	1.34732	.76964	1.29931	.79781	1.25343	.82678	1.20951	25
36	.71593	1.39679	.74267	1.34650	.77010	1.29853	.79829	1.25268	.82727	1.20879	24
37	.71637	1.39593	.74312	1.34568	.77057	1.29775	.79877	1.25193	.82776	1.20808	23
38	.71681	1.39507	.74357	1.34487	.77103	1.29696	.79924	1.25118	.82825	1.20736	22
39	.71725	1.39421	.74402	1.34405	.77149	1.29618	.79972	1.25044	.82874	1.20665	21
40	.71769	1.39336	.74447	1.34323	.77196	1.29541	.80020	1.24969	.82923	1.20593	20
41	.71813	1.39250	.74492	1.34242	.77242	1.29463	.80067	1.24895	.82972	1.20522	19
42	.71857	1.39165	.74538	1.34160	.77289	1.29385	.80115	1.24820	.83022	1.20451	18
43	.71901	1.39079	.74583	1.34079	.77335	1.29307	.80163	1.24746	.83071	1.20379	17
44	.71946	1.38994	.74628	1.33998	.77382	1.29229	.80211	1.24672	.83120	1.20308	16
45	.71990	1.38909	.74674	1.33916	.77428	1.29152	.80258	1.24597	.83169	1.20237	15
46	.72034	1.38824	.74719	1.33835	.77475	1.29074	.80306	1.24523	.83218	1.20166	14
47	.72078	1.38738	.74764	1.33754	.77521	1.28997	.80354	1.24449	.83268	1.20095	13
48	.72122	1.38653	.74810	1.33673	.77568	1.28919	.80402	1.24375	.83317	1.20024	12
49	.72167	1.38568	.74855	1.33592	.77615	1.28842	.80450	1.24301	.83366	1.19953	11
50	.72211	1.38484	.74900	1.33511	.77661	1.28764	.80498	1.24227	.83415	1.19882	10
51	.72255	1.38399	.74946	1.33430	.77708	1.28687	.80546	1.24153	.83465	1.19811	9
52	.72299	1.38314	.74991	1.33349	.77754	1.28610	.80594	1.24079	.83514	1.19740	8
53	.72344	1.38229	.75037	1.33268	.77801	1.28533	.80642	1.24005	.83564	1.19669	7
54	.72388	1.38145	.75082	1.33187	.77848	1.28456	.80690	1.23931	.83613	1.19599	6
55	.72432	1.38060	.75128	1.33107	.77895	1.28379	.80738	1.23858	.83662	1.19528	5
56	.72477	1.37976	.75173	1.33026	.77941	1.28302	.80786	1.23784	.83712	1.19457	4
57	.72521	1.37891	.75219	1.32946	.77988	1.28225	.80834	1.23710	.83761	1.19387	3
58	.72565	1.37807	.75264	1.32865	.78035	1.28148	.80882	1.23637	.83811	1.19316	2
59	.72610	1.37722	.75310	1.32785	.78082	1.28071	.80930	1.23563	.83860	1.19246	1
60	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490	.83910	1.19175	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	54°		53°		52°		51°		50°		

Natural Tangents and Cotangents.

′	40°		41°		42°		43°		44°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.83910	1.19175	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	60
1	.83960	1.19105	.86980	1.14969	.90093	1.10996	.93306	1.07174	.96625	1.03493	59
2	.84009	1.19035	.87031	1.14902	.90146	1.10931	.93360	1.07112	.96681	1.03433	58
3	.84059	1.18964	.87082	1.14834	.90199	1.10867	.93415	1.07049	.96738	1.03372	57
4	.84108	1.18894	.87133	1.14767	.90251	1.10802	.93469	1.06987	.96794	1.03312	56
5	.84158	1.18824	.87184	1.14699	.90304	1.10737	.93524	1.06925	.96850	1.03252	55
6	.84208	1.18754	.87236	1.14632	.90357	1.10672	.93578	1.06862	.96907	1.03192	54
7	.84258	1.18684	.87287	1.14565	.90410	1.10607	.93633	1.06800	.96963	1.03132	53
8	.84307	1.18614	.87338	1.14498	.90463	1.10543	.93688	1.06738	.97020	1.03072	52
9	.84357	1.18544	.87389	1.14430	.90516	1.10478	.93742	1.06676	.97076	1.03012	51
10	.84407	1.18474	.87441	1.14363	.90569	1.10414	.93797	1.06613	.97133	1.02952	50
11	.84457	1.18404	.87492	1.14296	.90621	1.10349	.93852	1.06551	.97189	1.02892	49
12	.84507	1.18334	.87543	1.14229	.90674	1.10285	.93906	1.06489	.97246	1.02832	48
13	.84556	1.18264	.87595	1.14162	.90727	1.10220	.93961	1.06427	.97302	1.02772	47
14	.84606	1.18194	.87646	1.14095	.90781	1.10156	.94016	1.06365	.97359	1.02713	46
15	.84656	1.18125	.87698	1.14028	.90834	1.10091	.94071	1.06303	.97416	1.02653	45
16	.84706	1.18055	.87749	1.13961	.90887	1.10027	.94125	1.06241	.97472	1.02593	44
17	.84756	1.17986	.87801	1.13894	.90940	1.09963	.94180	1.06179	.97529	1.02533	43
18	.84806	1.17916	.87852	1.13828	.90993	1.09899	.94235	1.06117	.97586	1.02474	42
19	.84856	1.17846	.87904	1.13761	.91046	1.09834	.94290	1.06056	.97643	1.02414	41
20	.84906	1.17777	.87955	1.13694	.91099	1.09770	.94345	1.05994	.97700	1.02355	40
21	.84956	1.17708	.88007	1.13627	.91153	1.09706	.94400	1.05932	.97756	1.02295	39
22	.85006	1.17638	.88059	1.13561	.91206	1.09642	.94455	1.05870	.97813	1.02236	38
23	.85057	1.17569	.88110	1.13494	.91259	1.09578	.94510	1.05809	.97870	1.02176	37
24	.85107	1.17500	.88162	1.13428	.91313	1.09514	.94565	1.05747	.97927	1.02117	36
25	.85157	1.17430	.88214	1.13361	.91366	1.09450	.94620	1.05685	.97984	1.02057	35
26	.85207	1.17361	.88265	1.13295	.91419	1.09386	.94676	1.05624	.98041	1.01998	34
27	.85257	1.17292	.88317	1.13228	.91473	1.09322	.94731	1.05562	.98098	1.01939	33
28	.85308	1.17223	.88369	1.13162	.91526	1.09258	.94786	1.05501	.98155	1.01879	32
29	.85358	1.17154	.88421	1.13096	.91580	1.09195	.94841	1.05439	.98213	1.01820	31
30	.85408	1.17085	.88473	1.13029	.91633	1.09131	.94896	1.05378	.98270	1.01761	30
31	.85458	1.17016	.88524	1.12963	.91687	1.09067	.94952	1.05317	.98327	1.01702	29
32	.85509	1.16947	.88576	1.12897	.91740	1.09003	.95007	1.05255	.98384	1.01642	28
33	.85559	1.16878	.88628	1.12831	.91794	1.08940	.95062	1.05194	.98441	1.01583	27
34	.85609	1.16809	.88680	1.12765	.91847	1.08876	.95118	1.05133	.98499	1.01524	26
35	.85660	1.16741	.88732	1.12699	.91901	1.08813	.95173	1.05072	.98556	1.01465	25
36	.85710	1.16672	.88784	1.12633	.91955	1.08749	.95229	1.05010	.98613	1.01406	24
37	.85761	1.16603	.88836	1.12567	.92008	1.08686	.95284	1.04949	.98671	1.01347	23
38	.85811	1.16535	.88888	1.12501	.92062	1.08622	.95340	1.04888	.98728	1.01288	22
39	.85862	1.16466	.88940	1.12435	.92116	1.08559	.95395	1.04827	.98786	1.01229	21
40	.85912	1.16398	.88992	1.12369	.92170	1.08496	.95451	1.04766	.98843	1.01170	20
41	.85963	1.16329	.89045	1.12303	.92224	1.08432	.95506	1.04705	.98901	1.01112	19
42	.86014	1.16261	.89097	1.12238	.92277	1.08369	.95562	1.04644	.98958	1.01053	18
43	.86064	1.16192	.89149	1.12172	.92331	1.08306	.95618	1.04583	.99016	1.00994	17
44	.86115	1.16124	.89201	1.12106	.92385	1.08243	.95673	1.04522	.99073	1.00935	16
45	.86166	1.16056	.89253	1.12041	.92439	1.08179	.95729	1.04461	.99131	1.00876	15
46	.86216	1.15987	.89306	1.11975	.92493	1.08116	.95785	1.04401	.99189	1.00818	14
47	.86267	1.15919	.89358	1.11909	.92547	1.08053	.95841	1.04340	.99247	1.00759	13
48	.86318	1.15851	.89410	1.11844	.92601	1.07990	.95897	1.04279	.99304	1.00701	12
49	.86368	1.15783	.89463	1.11778	.92655	1.07927	.95952	1.04218	.99362	1.00642	11
50	.86419	1.15715	.89515	1.11713	.92709	1.07864	.96008	1.04158	.99420	1.00583	10
51	.86470	1.15647	.89567	1.11648	.92763	1.07801	.96064	1.04097	.99478	1.00525	9
52	.86521	1.15579	.89620	1.11582	.92817	1.07738	.96120	1.04036	.99536	1.00467	8
53	.86572	1.15511	.89672	1.11517	.92872	1.07676	.96176	1.03976	.99594	1.00408	7
54	.86623	1.15443	.89725	1.11452	.92926	1.07613	.96232	1.03915	.99652	1.00350	6
55	.86674	1.15375	.89777	1.11387	.92980	1.07550	.96288	1.03855	.99710	1.00291	5
56	.86725	1.15308	.89830	1.11321	.93034	1.07487	.96344	1.03794	.99768	1.00233	4
57	.86776	1.15240	.89883	1.11256	.93088	1.07425	.96400	1.03734	.99826	1.00175	3
58	.86827	1.15172	.89935	1.11191	.93143	1.07362	.96457	1.03674	.99884	1.00116	2
59	.86878	1.15104	.89988	1.11126	.93197	1.07299	.96513	1.03613	.99942	1.00058	1
60	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	1.00000	1.00000	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	49°		48°		47°		46°		45°		

AREAS AND CIRCUMFERENCES OF CIRCLES

Diameter Inches	Circumference Inches	Area Sq Inches	Diameter Inches	Circumference Inches	Area Sq. Inches
1/16	.19635	.00307	2	6.28319	3.14:6
1/8	.392699	.01227	2 1/16	6.47953	3.3410
3/16	.589049	.02761	2 1/8	6.67588	3.5466
1/4	.785398	.04909	2 3/16	6.87223	3.7583
5/16	.981748	.07670	2 1/4	7.06858	3.9761
3/8	1.17810	.11045	2 5/16	7.26493	4.2000
7/16	1.37445	.15033	2 3/8	7.46128	4.4301
1/2	1.57080	.19635	2 7/16	7.65763	4.6664
9/16	1.76715	.24850	2 1/2	7.85398	4.9087
5/8	1.96350	.30680	2 9/16	8.05033	5.1572
1 1/16	2.15984	.37122	2 5/8	8.24668	5.4119
3/4	2.35619	.44179	2 11/16	8.44303	5.6727
1 3/16	2.55254	.51849	2 3/4	8.63938	5.9396
7/8	2.74889	.60132	2 13/16	8.83573	6.2126
1 5/16	2.94524	.69029	2 7/8	9.03208	6.4918
1	3.14159	.7854	2 15/16	9.22843	6.7771
1 1/16	3.33794	.88664	3	9.42478	7.0686
1 1/8	3.53429	.99402	3 1/16	9.62113	7.3662
1 3/16	3.73064	1.1075	3 1/8	9.81748	7.6699
1 1/4	3.92699	1.2272	3 3/16	10.0138	7.9798
1 5/16	4.12334	1.3530	3 1/4	10.2102	8.2958
1 3/8	4.31969	1.4849	3 5/16	10.4065	8.6179
1 7/16	4.51604	1.6230	3 3/8	10.6029	8.9462
1 1/2	4.71239	1.7671	3 7/16	10.7992	9.2806
1 9/16	4.90874	1.9175	3 1/2	10.9956	9.6211
1 5/8	5.10509	2.0739	3 9/16	11.1919	9.9678
1 11/16	5.30144	2.2365	3 5/8	11.3883	10.321
1 3/4	5.49779	2.4053	3 11/16	11.5846	10.680
1 13/16	5.69414	2.5802	3 3/4	11.7810	11.045
1 7/8	5 89049	2.7612	3 13/16	11.9773	11.416
1 15/16	6.08684	2 9483	3 7/8	12.1737	11.793

AREAS AND CIRCUMFERENCES OF CIRCLES—continued

Diameter Inches	Circumference Inches	Area Sq. Inches	Diameter Inches	Circumference Inches	Area Sq. Inches
3 1/16	12.3700	12.177	5 1/8	18.4569	27.109
4	12.5664	12.566	5 1/16	18.6532	27.688
4 1/16	12.7627	12.962	6	18.8496	28.274
4 1/8	12.9591	13.364	6 1/8	19.2423	29.465
4 3/16	13.1554	13.772	6 1/4	19.6350	30.680
4 1/4	13.3518	14.186	6 3/8	20.0277	31.919
4 5/16	13.5481	14.607	6 1/2	20.4204	33.183
4 3/8	13.7445	15.033	6 5/8	20.8131	34.472
4 7/16	13.9408	15.466	6 3/4	21.2058	35.785
4 1/2	14.1372	15.904	6 7/8	21.5984	37.122
4 9/16	14.3335	16.349	7	21.9911	38.485
4 5/8	14.5299	16.800	7 1/8	22.3838	39.871
4 11/16	14.7262	17.257	7 1/4	22.7765	41.282
4 3/4	14.9226	17.721	7 3/8	23.1692	42.718
4 13/16	15.1189	18.190	7 1/2	23.5619	44.179
4 7/8	15.3153	18.665	7 5/8	23.9546	45.664
4 15/16	15.5116	19.147	7 3/4	24.3473	47.173
5	15.7080	19.635	7 7/8	24.7400	48.707
5 1/16	15.9043	20.129	8	25.1327	50.265
5 1/8	16.1007	20.629	8 1/8	25.5224	51.849
5 3/16	16.2970	21.135	8 1/4	25.9181	53.456
5 1/4	16.4934	21.648	8 3/8	26.3108	55.088
5 5/16	16.6897	22.166	8 1/2	26.7035	56.745
5 3/8	16.8861	22.691	8 5/8	27.0962	58.426
5 7/16	17.0824	23.221	8 3/4	27 4889	60.132
5 1/2	17.2788	23.758	8 7/8	27.8816	61.862
5 9/16	17.4751	24.301	9	28.2743	63.617
5 5/8	17.6715	24.850	9 1/8	28.6670	65.397
5 11/16	17.8678	25.406	9 1/4	29.0597	67.201
5 3/4	18.0642	25.967	9 3/8	29.4524	69.029
5 13/16	18.2605	26.535	9 1/2	29.8451	70.882

AREAS AND CIRCUMFERENCES OF CIRCLES—continued

Diameter Inches	Circumference Inches	Area Sq. Inches	Diameter Inches	Circumference Inch	Area Sq. Inches
9⅛	30.2378	72.760	10⅞	34.1648	92.886
9¼	30.6305	74.662	11	34.5575	95.033
9⅞	31.0233	76 589	11⅛	34.9502	97.205
10	31.4159	78.540	11¼	35.3429	99.402
10⅛	31.8086	80.516	11⅜	35.7356	101.62
10¼	32.2013	82.516	11½	36.1283	103.87
10⅜	32.5940	84.541	11⅝	36.5210	106.14
10½	32.9867	86.590	11¾	36.9137	108.43
10⅝	33.3794	88.664	11⅞	37.3064	110.75
10¾	33.7721	90.763	12	37.6991	113.10

AMERICAN STEAM, WATER, AND GAS PIPES

Size of Pipe Inches	Actual Outside Diameter Inches	Actual Inside Diameter Inches	Number of Threads per Inch of Screw
$\frac{1}{8}$	0.405	0.270	27
$\frac{1}{4}$	0.54	0.364	18
$\frac{3}{8}$	0.675	0.494	18
$\frac{1}{2}$	0.84	0.623	14
$\frac{3}{4}$	1.05	0.824	14
1	1.315	1.048	$11\frac{1}{2}$
$1\frac{1}{4}$	1.66	1.380	$11\frac{1}{2}$
$1\frac{1}{2}$	1.9	1.611	$11\frac{1}{2}$
2	2.375	2.067	$11\frac{1}{2}$
$2\frac{1}{2}$	2.875	2.468	8
3	3.5	3.067	8
$3\frac{1}{2}$	4	3.548	8
4	4.5	4.026	8
$4\frac{1}{2}$	5	4.508	8
5	5.563	5.045	8
6	6.625	6.065	8
7	7.625	7.023	8
8	8.625	7.982	8

Table of Decimal Equivalents

OF

8ths, 16ths, 32ds, and 64ths of an Inch.

8ths.

$\frac{1}{8}$ = .125
$\frac{2}{8}$ = .250
$\frac{3}{8}$ = .375
$\frac{4}{8}$ = .500
$\frac{5}{8}$ = .625
$\frac{6}{8}$ = .750
$\frac{7}{8}$ = .875

16ths.

$\frac{1}{16}$ = .0625
$\frac{3}{16}$ = .1875
$\frac{5}{16}$ = .3125
$\frac{7}{16}$ = .4375
$\frac{9}{16}$ = .5625
$\frac{11}{16}$ = .6875
$\frac{13}{16}$ = .8125
$\frac{15}{16}$ = .9375

32ds.

$\frac{1}{32}$ = .03125
$\frac{3}{32}$ = .09375
$\frac{5}{32}$ = .15625
$\frac{7}{32}$ = .21875
$\frac{9}{32}$ = .28125
$\frac{11}{32}$ = .34375
$\frac{13}{32}$ = .40625
$\frac{15}{32}$ = .46875
$\frac{17}{32}$ = .53125
$\frac{19}{32}$ = .59375
$\frac{21}{32}$ = .65625
$\frac{23}{32}$ = .71875
$\frac{25}{32}$ = .78125
$\frac{27}{32}$ = .84375
$\frac{29}{32}$ = .90625
$\frac{31}{32}$ = .96875

64ths.

$\frac{1}{64}$ = .015625
$\frac{3}{64}$ = .046875
$\frac{5}{64}$ = .078125
$\frac{7}{64}$ = .109375
$\frac{9}{64}$ = .140625
$\frac{11}{64}$ = .171875
$\frac{13}{64}$ = .203125
$\frac{15}{64}$ = .234375
$\frac{17}{64}$ = .265625
$\frac{19}{64}$ = .296875
$\frac{21}{64}$ = .328125
$\frac{23}{64}$ = .359375
$\frac{25}{64}$ = .390625
$\frac{27}{64}$ = .421875
$\frac{29}{64}$ = .453125
$\frac{31}{64}$ = .484375
$\frac{33}{64}$ = .515625
$\frac{35}{64}$ = .546875
$\frac{37}{64}$ = .578125
$\frac{39}{64}$ = .609375
$\frac{41}{64}$ = .640625
$\frac{43}{64}$ = .671875
$\frac{45}{64}$ = .703125
$\frac{47}{64}$ = .734375
$\frac{49}{64}$ = .765625
$\frac{51}{64}$ = .796875
$\frac{53}{64}$ = .828125
$\frac{55}{64}$ = .859375
$\frac{57}{64}$ = .890625
$\frac{59}{64}$ = .921875
$\frac{61}{64}$ = .953125
$\frac{63}{64}$ = .984375

Table of Decimal Equivalents
OF
Millimeters and Fractions of Millimeters.

$\frac{1}{100}$ mm. = .0003937 inch.

mm.	inches.	mm.	inches.	mm.	inches.
$\frac{1}{50}$	= .00079	$\frac{26}{50}$	= .02047	2	= .07874
$\frac{2}{50}$	= .00157	$\frac{27}{50}$	= .02126	3	= .11811
$\frac{3}{50}$	= .00236	$\frac{28}{50}$	= .02205	4	= .15748
$\frac{4}{50}$	= .00315	$\frac{29}{50}$	= .02283	5	= .19685
$\frac{5}{50}$	= .00394	$\frac{30}{50}$	= .02362	6	= .23622
$\frac{6}{50}$	= .00472	$\frac{31}{50}$	= .02441	7	= .27559
$\frac{7}{50}$	= .00551	$\frac{32}{50}$	= .02520	8	= .31496
$\frac{8}{50}$	= .00630	$\frac{33}{50}$	= .02598	9	= .35433
$\frac{9}{50}$	= .00709	$\frac{34}{50}$	= .02677	10	= .39370
$\frac{10}{50}$	= .00787	$\frac{35}{50}$	= .02756	11	= .43307
$\frac{11}{50}$	= .00866	$\frac{36}{50}$	= .02835	12	= .47244
$\frac{12}{50}$	= .00945	$\frac{37}{50}$	= .02913	13	= .51181
$\frac{13}{50}$	= .01024	$\frac{38}{50}$	= .02992	14	= .55118
$\frac{14}{50}$	= .01102	$\frac{39}{50}$	= .03071	15	= .59055
$\frac{15}{50}$	= .01181	$\frac{40}{50}$	= .03150	16	= .62992
$\frac{16}{50}$	= .01260	$\frac{41}{50}$	= .03228	17	= .66929
$\frac{17}{50}$	= .01339	$\frac{42}{50}$	= .03307	18	= .70866
$\frac{18}{50}$	= .01417	$\frac{43}{50}$	= .03386	19	= .74803
$\frac{19}{50}$	= .01496	$\frac{44}{50}$	= .03465	20	= .78740
$\frac{20}{50}$	= .01575	$\frac{45}{50}$	= .03543	21	= .82677
$\frac{21}{50}$	= .01654	$\frac{46}{50}$	= .03622	22	= .86614
$\frac{22}{50}$	= .01732	$\frac{47}{50}$	= .03701	23	= .90551
$\frac{23}{50}$	= .01811	$\frac{48}{50}$	= .03780	24	= .94488
$\frac{24}{50}$	= .01890	$\frac{49}{50}$	= .03858	25	= .98425
$\frac{25}{50}$	= .01969	1	= .03937	26	= 1.02362

10 mm. = 1 Centimeter = 0.3937 inches.
10 cm. = 1 Decimeter = 3.937 "
10 dm. = 1 Meter = 39.37 "
25.4 mm. = 1 English Inch.

Tap Drills.

For Taps ¼ to 2 Inches.

Diam. of Tap	No. Threads to Inch.			Drill for V Thread.		
¼	16	18	20	5/32	5/32	11/64
5/32	16	18	20	9/64	13/64	13/64
3/16	16	18	..	7/32	15/64	..
7/32	16	18	..	¼	17/64	..
3/8	14	16	18	¼	9/32	5/32
9/32	14	16	18	17/64	21/64	21/64
5/16	14	16	..	21/64	11/32	..
11/32	14	16	..	23/64	3/8	..
3/8	12	13	14	3/8	25/64	25/64
13/32	12	13	14	13/32	27/64	27/64
7/16	12	14	..	7/16	29/64	..
15/32	12	14	..	15/32	31/64	..
7/8	10	11	12	15/32	½	½
17/32	10	11	12	½	17/32	17/32
11/16	11	12	..	9/16	9/16	..
23/32	11	12	..	19/32	19/32	..
¾	10	11	12	19/32	5/8	5/8
25/32	10	11	12	5/8	21/32	21/32
13/16	10	..	..	21/32	..	..
27/32	10	..	..	11/16	..	..
7/8	9	10	..	43/64	23/32	..
29/32	9	10	..	47/64	¾	..
15/16	9	..	..	49/64	..	..
31/32	9	..	.	51/64	..	..
1	8	..	..	13/16	..	..
1 1/32	8	..	..	53/64	..	..
1 1/8	7	8	..	55/64	29/32	..
1 5/32	7	8	..	15/16	31/32	..
1 ¼	7	..	..	1 1/32	..	..
1 9/32	7	..	..	1 1/16	..	..
1 3/8	6	..	..	1 1/8	..	..
1 13/32	6	..	..	1 5/32	..	..
1 ½	6	..	..	1 15/64	..	..
1 17/32	6	..	..	1 9/32	..	..
1 5/8	5	5½	..	1 5/32	1 7/16	..
1 21/32	5	5½	..	1 5/16	1 11/32	..
1 ¾	5	..	..	1 13/32	..	..
1 29/32	5	..	..	1 7/8	..	.
1 7/8	4½	5	..	1 17/32	1 17/32	..
1 29/32	4½	5	..	1 9/16	1 9/16	.
2	4½	..	..	1 21/32	..	..

American or Brown & Sharpe

Twist Drill and Steel Wire Gauge.

No.	Dia.	No.	Dia.	No.	Dia.	No.	Dia.
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.02925
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

Table of Average Cutting Speed for Drills.

Dia. Drill	Speed Mach. Steel	Speed Cast Iron	Speed for Brass	Dia. Drill	Speed Mach. Steel	Speed Cast Iron	Speed for Brass
1/16	1820	2430	3640	1 1/16	81	114	186
1/8	895	1200	1820	1 1/8	76	105	175
3/16	589	790	1200	1 3/16	70	98	164
1/4	433	685	888	1 1/4	65	92	154
5/16	343	462	705	1 5/16	61	86	145
3/8	280	379	585	1 3/8	57	81	137
7/16	237	320	495	1 7/16	53	76	130
1/2	204	277	430	1 1/2	50	71	124
9/16	178	242	379	1 9/16	47	67	118
5/8	157	215	338	1 5/8	44	63	112
11/16	142	193	305	1 11/16	41	60	107
3/4	127	174	277	1 3/4	39	57	102
13/16	115	158	353	1 13/16	36	54	97
7/8	105	145	233	1 7/8	34	51	93
15/16	96	133	216	1 15/16	32	48	89
	89	123	200	2	30	46	86

Wire Gauge Used in the United States.

Dimensions of Sizes in Decimal Parts of an Inch.

Number of Wire Gauge.	American or B. & S.	Birmingham or Stub's.	Washburn & Moen Mfg. Co.	Number of Wire Gauge.
000000	.....	....	.46	000000
00000	.....	....	.43	00000
0000	.46	.454	.393	0000
000	.40964	.425	.362	000
00	.3648	.38	.331	00
0	.32486	.34	.307	0
1	.2893	.3	.283	1
2	.25763	.284	.263	2
3	.22942	.259	.244	3
4	.20431	.238	.225	4
5	.18194	.22	.207	5
6	.16202	.203	.192	6
7	.14428	.18	.177	7
8	.12849	.165	.162	8
9	.11443	.148	.148	9
10	.10189	.134	.135	10
11	.090742	.12	.12	11
12	.080808	.109	.105	12
13	.071961	.095	.092	13
14	.064084	.083	.08	14
15	.057068	.072	.072	15
16	.05082	.065	.063	16
17	.045257	058	.054	17
18	.040303	.049	.047	18
19	.03589	.042	.041	19
20	.031961	.035	.035	20
21	.028462	.032	.032	21
22	.025347	.028	.028	22
23	.022571	.025	.025	23
24	.0201	.022	.023	24
25	.0179	.02	.02	25
26	.01594	.018	.018	26
27	.014195	.016	.017	27
28	.012641	.014	.016	28
29	.011257	.013	.015	29
30	.010025	.012	.014	30
31	.008928	.01	.0135	31
32	.00795	.009	.013	32
33	.00708	.008	.011	33
34	.006304	.007	.01	34
35	.005614	.005	.0095	35
36	.005	.004	.009	36
37	.004453	....	.0085	37
38	.003965	....	.008	38
39	.003531	....	.0075	39
40	.003144	....	.007	40

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